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VOLUME 31

B. GENERAL SECTION

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NUMBER 1

THE AUSTRALIAN CARPET BEETLE, *Anthrenocerus australis* (HOPE), IN NEW ZEALAND

By PHYLLIS L. ROBERTSON, Entomological Research Station, Nelson

(Received for publication, 22 August 1949)

Summary

1. The Australian Carpet Beetle, *Anthrenocerus australis* (Hope), is recorded as a household pest in New Zealand.

2. Its world distribution is referred to and the synonymy of the species is outlined.

3. Diagnostic characters are given for the separation of the adult from the genus *Trogoderma*, to which it is closest morphologically, from *Attagenus* with which it is often associated in infestations, and from *Anthrenus*, the other carpet beetle genus already represented in New Zealand.

4. Diagnostic characters are given for the separation of the larva from the same three genera, and further morphological details of the larvæ are described.

5. The economic importance of *A. australis* in New Zealand and its control are discussed.

INTRODUCTION

For a number of years it has been known that *Anthrenus verbasci* (L.) is not the only species of carpet beetle established in New Zealand. Numerous specimens of larvæ differing markedly from those of *A. verbasci* have been forwarded to this laboratory from a number of localities in both the North and South Islands. The larvæ are of the *Trogoderma* type, but have proved difficult to rear in the laboratory. During the past season, however, a number of adults have emerged from infestations being held for rearing by this Station and these have proved to be the Australian Carpet Beetle, *Anthrenocerus australis* (Hope), Family Dermestidae. The identification of this species has provided an explanation for the difficulty of obtaining adults in the laboratory. All the larvæ forwarded to the Station have been recorded as pests of woollen goods and attempts to rear them have always been on such materials. According to Evans (1943), however, the species takes two years to develop on wool, etc., and the life cycle is reduced to one year only when dried insects, fish meal, or some such animal matter, is provided as food. The difficulty of obtaining adults from insects with such a protracted life cycle has, in this case, been increased by the fact that, unless emerging adults were removed from cultures quickly, dead specimens would probably have been eaten by any larvæ remaining.

Early records of *A. australis* are confused and the first recognized description, under the genus *Anthrenus*, was by Hope in 1843. The type of his species was from Adelaide, and is held by the Oxford Museum. In 1915 Arrow designated *A. australis* the type of a new genus, *Anthrenocerus*, which he considered to be confined to Australia. He pointed out that he had examined Hope's type material of *A. australis* and believed it "to be the species later described as *Trogoderma rignum* Er." However, Arrow appears to have been mistaken in the date of this description, which Erichson published in *Archiv für Naturg.* viii (1), p. 152, 1842. If Arrow is correct in his opinion, *australis* should be relegated to synonymy and the species should become *Anthrenocerus rignum*. However, Erichson's description is vague and indeterminate and it appears that his type material was not examined by Arrow. It is probable that the type described by Erichson, which was from Tasmania, was deposited originally in the former Museum für Naturkunde, Königlich-Friedrich-Wilhelms-Universität, Berlin, so that it may prove impossible to discover whether the type is still in existence and, even if it is, where it is at present located. Until, or unless, the present species can be compared with the type of *T. rignum* described by Erichson, evidence is probably not sufficiently strong to warrant a change of the specific name *australis*.

It is possible that *A. australis* has been present in New Zealand for many years and may even have been described by one of the early workers such as Broun as a native New Zealand Dermestid. Mr. E. S. Gourlay, Cawthron Institute, has pointed out that *Trogoderma punctata* Broun, described in 1886, is probably a synonym of *Anthrenocerus australis*, but Broun's description is not sufficiently detailed to place this beyond doubt. At present an effort is being made to have the point clarified by the British Museum, which is holding the collection of Broun types of New Zealand Coleoptera.

In economic literature *A. australis* has been recorded as a serious pest only in Australia. Evans (1942 and 1943) considered the species to be the most common carpet beetle in Tasmania, and to be responsible for much more damage in houses than are clothes moths. Jenkins (1944) also referred to *A. australis* as being one of the commonest carpet beetles in Western Australia.

About 1933, the occurrence of *A. australis* in England was first noted. Wakely (1936) recorded the species as having been breeding for three or four years in a printing works, and Howe (1939) stated that he had obtained larvæ from the London wharf in 1933 on hides. Hinton (1945) has not recorded further outbreaks of the species in England, so that it does not appear to have become widely distributed there.

According to present knowledge of *A. australis* in New Zealand, the species is probably much more widespread in New Zealand than it is in England, and in fact may approach the status it has attained in Australia as one of the most injurious household pests attacking fabrics.

SYNONYMY

Anthrenocerus australis Hope, *Ann. Mag. nat. Hist.* 11, p. 319, 1843 (*Anthrenus*); *Trans. ent. Soc. Lond.* 4, p. 105, 1845 (*Anthrenis*); Blackburn, *Trans. roy. Soc. S. Aust.* 14, p. 132, 1891 (*Anthrenus*); *Ibid.* 28, p. 169, 1903 (*Cryptorhopalum*); Dalla Torre, *Col. Cat. (Junk)*, Pars 33, p. 73, 1911 (*Cryptorhopalum*); Arrow, *Ann. Mag. nat. Hist. (Ser. 8)*, 15, p. 443, 1915 (*Anthrenocerus* n.g.);

Hinton, "Monograph of the Beetles associated with stored products," 1, p. 369, 1945.

Cryptorhopalum crichsoni Reitter, *Verh. naturf. Ver. Brunn*, 19, 1880, (1881), pp. 55, 56.

THE ADULT

The adult *Anthrenocerus australis* has been described by Hinton (1945). It is of importance to be able to separate it first from *Anthrenus verbasci*, the only other carpet beetle so far recorded in New Zealand. The two are small dermestid beetles of approximately the same size, the length of *A. verbasci* being 1.7 - 3.2 mm., and that of *A. australis*, 2.0 - 3.4 mm., according to Hinton. They are, however, so conspicuously different in colour pattern as to make the species readily separable. *A. australis* is black in colour, the body is covered with dark brown or black hairs, and is marked by a pattern of white or yellowish-white hairs on the pronotum and running in three narrow, zig-zag bands across the elytra (see Fig. 1). *A. verbasci* has the body covered not with hairs

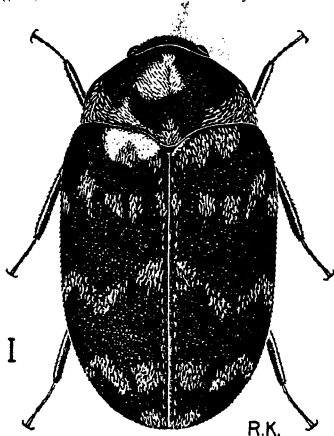


FIG. 1.—Adult of *Anthrenocerus australis* (after Evans).

but with scales, forming a variegated pattern on the dorsal surface, which is considerably lighter in colour than in the case of *A. australis*. The background scales are brown or black, while the head is almost entirely clothed with yellowish scales, and a conspicuous pattern of white and yellowish patches covers the pronotum and elytra (see Fig. 2).

The family Dermestidae is divided by Hinton and other modern coleopterists into six subfamilies, viz., Dermestinae, Orphilinae, Trinodinae, Thylodriinae, Attageninae and Anthreninae; the common carpet beetles fall into the latter two subfamilies. The genera *Anthrenocerus*

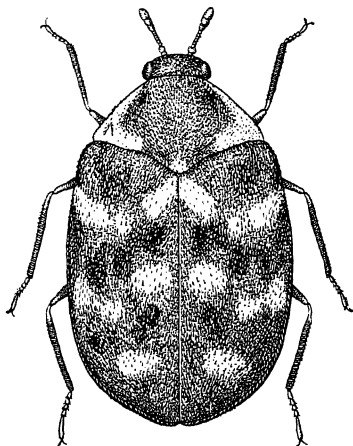


FIG. 2.—Adult of *Anthrenus verbasci* (after Hinton).

and *Anthrenus* both belong to the Anthreninae, as does *Trogoderma*, the genus to which *Anthrenocerus* is most closely allied morphologically and under which Broun has described several endemic species. A further genus which has not yet been recorded in New Zealand, but which may well prove to be present, is *Attagenus*,* known in both Australia and England to occur in association with *Anthrenocerus*. The following key, derived from Hinton (1945), will serve to differentiate adults of *Anthrenocerus* from those of the other three important genera, *Trogoderma*, *Attagenus* and *Anthrenus*.

1. Body clothed with oval scales; elytral epipleuron feebly developed near base, elsewhere absent; metasternal epimeron not visible externally; hind coxa extending as far as the metasternal episternum (Fig. 3) *Anthrenus*
- Body clothed with hairs; elytral epipleuron well developed particularly in basal half; metasternal epimeron large and externally visible; hind coxa extending approximately half way across caudal margin of metasternal episternum (Fig. 4) 2
2. Hind tarsus with basal segment half, or less than half, as long as second *Attagenus*
- Hind tarsus with basal segment as long as or longer than second 3.

* Since going to press a paper by R. A. Harrison has been published, entitled "Tests with DDT and Gammexane on the larvae of a dermestid beetle (*Attagenus* sp.), a pest in some New Zealand woollen mills." *N.Z. J. Sci. and Tech.*, 30 (Sec. A), 1948 (1949), 100-4. As *Anthrenocerus australis* has been confused with *Attagenus* in New Zealand, it seems possible that the former may have been the species concerned in these tests.

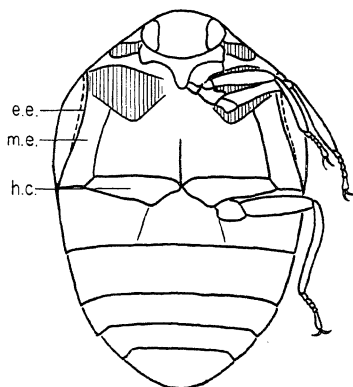


FIG. 3.—Diagram of ventral surface of adult of *A. verbasci*, showing relationship of thoracic sclerites. e.e.—elytral epipleuron; h.c.—hind coxa; m.e.—metasternal episternum.

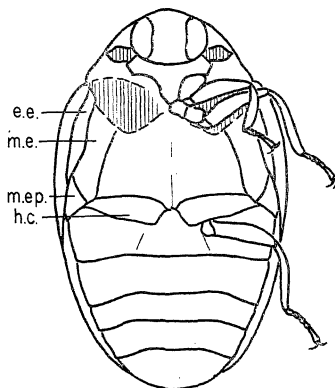


FIG. 4.—Diagram of ventral surface of adult of *A. australis*. m.ep.—metasternal epimeron.

3. Antennal club nearly always more than 3-segmented in both sexes, usually 4-segmented in females and 5- to 7-segmented in males (Fig. 5), segments of club often serrate, and sometimes even flabellate *Trogoderma*
- Antennal club large, abrupt, subparallel, of 3 closely fitting, sub-equal segments in both sexes (Fig. 6) *Anthrenocerus*

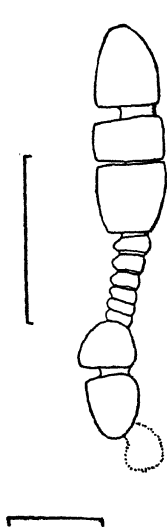


Fig. 5

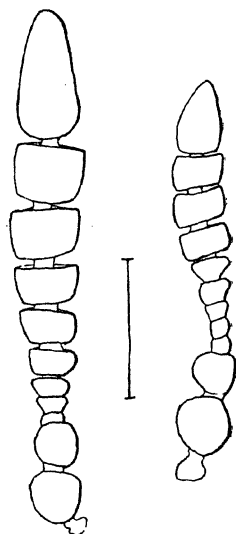


Fig. 6

FIG. 5.—Antenna of adult of *A. australis* (after Hinton).

FIG. 6.—Antenna of adult of *Trogoderma versicolor* (after Hinton).

THE LARVA

From an economic viewpoint, the larval stage is the most important in the life cycle of *Anthrenocerus australis*, as this is the stage which causes serious damage to woollen goods. Larvæ are always forwarded for identification and it is of considerable value to be able to identify the species without rearing adults. Up to the present there has been little published information on the structure of the larva. Evans (1942 and 1943) and Jenkins (1944) referred to the larvæ without giving morphological details, and only Blair (1936) and Hinton (1945) have described structural features such as the arrangement of body setae, the antenna, the maxilla, etc.

The larva of *A. australis* can be distinguished readily from that of *A. verbasci* on several gross characters, the most obvious of which is the shape of the body. In *A. verbasci* the body becomes gradually wider towards the posterior end, the greatest width being about the fourth abdominal segment (Fig. 7). Beyond this the terminal segments are somewhat telescoped and are hidden dorsally by heavy brushes of setae. In *A. australis*, on the other hand, the greatest width of the body is about the thorax, and it tapers gradually towards the caudal end without any telescoping of segments (Fig. 8).

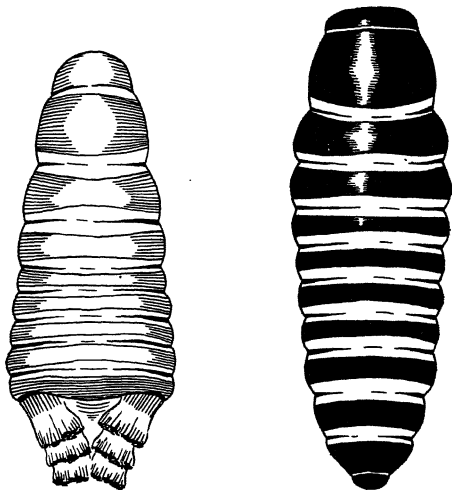


FIG. 7.—Diagram of body shape of larva of *A. verbasci*.

FIG. 8.—Diagram of body shape of larva of *A. australis*.

There is a further marked difference between the species in the pigmentation of the dorsal body cuticle. In *A. verbasci* the tergites are light brown, and those of the prothoracic and 5th abdominal segments only slightly darker. In contrast, the tergites in *A. australis* are very dark brown to black, and as the membranous intervals between them are without pigmentation, a conspicuous pattern is formed along the body of alternating black and white transverse bands.

It is necessary to make microscopic slide preparations in order to check the characters separating *Anthrenocerus* larvae from those of *Trogoderma* and *Attagenus* in addition to *Anthrenus*. However, the technique involved is simple. Some of the larvae used in the present studies were left in KOH for 24 hours, washed in distilled water, dehydrated and mounted in Euparal, or washed, transferred to water plus

ascetic acid and mounted in Berlese's fluid. Later it was found that, by working with cast skins instead of the larvæ themselves, preliminary preparation could be eliminated. At ecdysis, skins are split down the mid-dorsal line and head, mouthparts, legs, etc., remain intact, only the fragile, spear-headed setae of the body segments becoming detached. For microscopic examination the whole skin was placed directly on a slide in Berlese's fluid, polyvinyl alcohol mountant or Euparal, and antennæ, mouth parts, etc., were separated out before covering. The form and distribution of body setae were checked separately in preserved specimens of larvæ. The following key, based on simple microscopic characters which can be readily determined with the latter technique, will serve to separate the larva of *Anthrenocerus* from the three genera with which it is most likely to be confused:—

1. Body surface without spear-headed setae; maxillary palp 4-segmented; 5 ocelli on each side of head *Attagenus*
- Dorsal body surface bearing spear-headed setae; maxillary palp 3-segmented; 6 ocelli on each side of head 2.
2. Greatest width of body about 4th abdominal segment; tufts of spear-headed setae on 5th to 7th abdominal segments arising from membranous posterior regions of segments, while corresponding tergites are emarginate laterally and curved about bases of tufts (Fig. 9) *Anthrenus*

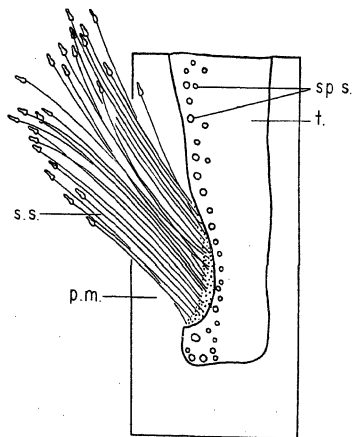


FIG. 9.—Diagram of lateral arrangement of setae on 5th abdominal segment of larva of *A. verbasci*. p.m.—posterior membrane; s.s.—spear-headed setae; sp.s.—sockets of spinulate setae; t.—tergite.

- Greatest width of body through thorax; 5th to 7th abdominal tergites not emarginate laterally and tufts of spear-headed setae arising from tergites themselves towards their posterior margins (Fig. 10) 3.

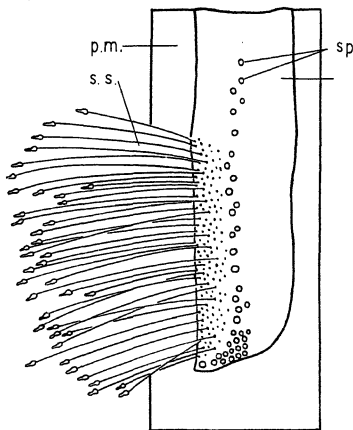


FIG. 10.—Diagram of lateral arrangement of setae on 5th abdominal segment of *A. australis*.

3. Antenna with second segment about twice as long as third and much more than twice as long as broad (Fig. 11) . . . *Anthrenocerus*
 — Antenna with second segment not more than half as long again as third and slightly to considerably less than twice as long as broad (Fig. 12) *Trogoderma*



FIG. 11.—Antenna of larva of *A. australis*.

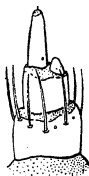


FIG. 12.—Antenna of larva of *Trogoderma versicolor* (after Rees).

Further details of the larval morphology of *Anthrenocerus australis* are as follows:—

Body Setae:

The vestiture of the body is one of the most conspicuous features of larvæ of the subfamily Anthreninae and characteristics of the group are well developed in the case of *A. australis*. Two distinct types of setae are produced, namely, spinulate setae (Fig. 13) and spear-headed setae (Fig. 14). The first have also been called "rat tail setae" by Ferris (1934), and these cover the ventral surface of the body, fringe the

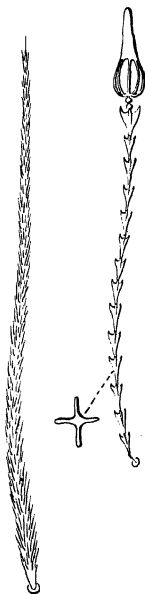


FIG. 13 (left).—Spinulate seta of Dermestid larva (after Ferris).

FIG. 14 (right).—Spear-headed seta of Dermestid larva (after Ferris).

anterior margin of the prothoracic tergite, form a line across the anterior half of the meso- and metathorax and across the centre of each abdominal tergite. The spinulate setae are comparatively coarse, with numerous fine lateral branches, and vary in length from less than 0.1 mm. to approximately 4.0 mm. Very long spinulate setae arise in strands at the terminal end of the body, forming a conspicuous "tail".

The spear-headed setae, also known as "hastisetæ" (Rees, 1943) and "pendicle setae" (Ferris, 1934), are found only in larvae of the Anthreninae. In *A. australis* they are produced on the dorsal surface of each segment in the body. They arise, in each case, from the chitinous tergite itself, posterior to the spinulate setae, and are aggregated into lateral tufts which become increasingly conspicuous towards the caudal end of the body. This arrangement differs from that found in *A. verbasci*. Here the spinulate setae arise towards the posterior margins of the tergites and, in the thorax and first four abdominal segments, the spear-headed setae are developed along the extreme posterior margins of the tergites but are not aggregated into lateral tufts. Conspicuous lateral tufts, or brushes, arise only on abdominal segments 5 to 7, and here the spear-headed setae originate not from the tergites but from the membranous areas posterior to them.

Antenna:

In *A. australis*, the antenna does not differ markedly in the relative length and width of its segments from that of *A. verbasci* (Fig. 15). The most obvious difference is in the development of the terminal papilla of the second segment. In *A. australis* this is reduced to a flattened disc, whereas in *A. verbasci* it projects beyond the base of the third segment as a well-developed lobe. Further, the basal segment of the antenna of *A. australis* bears six stout setae, while in *A. verbasci* only four comparatively slender setae are present. The difference in number of these setae may not be constant, but the contrast in their shape and thickness in the two species is always obvious.

The antenna of the larva of *Attagenus* (Fig. 16) is markedly different from those of all three genera, *Anthrenocerus*, *Anthrenus* and *Trogoderma*, particularly in the basal segment, which is long and slender, bearing a large number of fine setae.

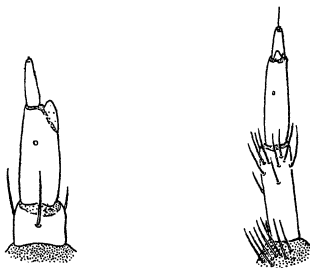


FIG. 15.—Antenna of larva of *A. verbasci* (after Rees).

FIG. 16.—Antenna of larva of *Attagenus piceus* (after Rees).

Mandible:

This does not show any unique features. The mandible is typical of the subfamily, having the apical half more strongly sclerotized than the basal half and dark brown in colour, and a tuft of long hairs on the outer margin of the basal half. The median membranous or sclerotized

process, called the retinaculum by Rees and the prostheca by Hinton, is absent in *A. australis*, as is the basal brush of setae which sometimes accompanies it. In all these features the mandible corresponds with that of *A. verbasci*.

Epipharynx:

Rees (1943) has made a detailed study of the larval epipharynx in the Dermestidae and has found that it shows several distinctive generic characters. That of *Anthrenocerus australis* (Fig. 17) differs from

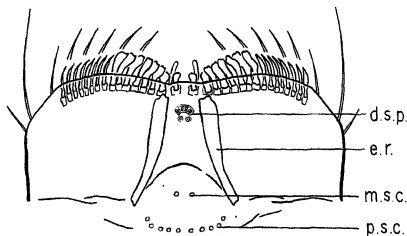


FIG. 17.—Epipharynx of larva of *A. australis*. d.s.p.—distal sensory papillae; e.r.—epipharyngeal rods; m.s.c.—median sensory cups; p.s.c.—proximal sensory cups.

any described by Rees, belonging to genera known to be represented in the United States. It bears six distal sensory papillae, four of these being arranged in a sharply defined, compact, crescentic area towards the distal margin of the epipharynx, while the remaining two are nearer the centre and widely separated. There is a median pair of sensory cups and a proximal, transverse series of about 10 sensory cups. The epipharyngeal rods are curved, enlarged distally and diverge towards their proximal ends.

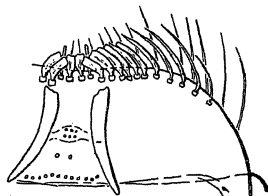


FIG. 18.—Epipharynx of larva of *A. verbasci* (after Rees).

In *Anthrenus verbasci* (Fig. 18) the six distal sensory papillae are not aggregated in a compact area, but are well separated from each other and are loosely grouped near the middle of the epipharynx. There is a median pair of sensory cups, as in *A. australis*, but the proximal series numbers about 12, instead of 10. According to Rees, the distal sensory papillae in *Trogoderma* are grouped in a single, sharply defined

compact area, while there are 10 to 20 sensory cups in the proximal transverse series. In *Attagenus* the distal sensory papillae are absent, while the proximal sensory area is composed of a transverse series of six large sensory papillae and a more proximal transverse series of 17 to 20 sensory cups.

ECONOMIC IMPORTANCE

Anthrenocerus australis is essentially a household pest and it is in this habitat that it is likely to present the most serious problem. During 1948 it has been recorded in New Zealand as attacking carpets, blankets, eiderdown quilts, knitting wool, woollen clothing and different kinds of cloth. It has been found breeding in cupboards, wardrobes, drawers, etc. Entomological Research Station records for 1948 show that specimens have been received for identification from the following localities:—

South Island: Burnside (Otago), Oamaru, Waimate, Timaru, Geraldine (Sth. Canterbury), Ashburton, Christchurch.

North Island: Taihape, Taupo, Hamilton, Mangapuhi (King Country).

The bulk of material has been forwarded from Timaru, where *A. australis* is regarded as a very serious pest. Apparently the species has a wide tolerance to temperature, but seems to thrive particularly well in a cool climate.

CONTROL

Carpet beetles present a difficult problem in control, as (a) they frequently attack fabrics liable to injury by sprays having an oil or kerosene base; (b) they attack clothing, and therefore cannot be eradicated by sprays or dusts which might act as skin irritants; (c) they breed in obscure cracks and corners which frequently can be reached only with difficulty; (d) as household pests they cannot conveniently be subjected to large scale fumigation.

No experiments have been carried out at this station in New Zealand on the control of *A. australis*, and measures at present being adopted follow those put forward by Dumbleton (1940) for *A. verbasci*. These are in general agreement with overseas recommendations against *A. australis*, *A. verbasci* and a number of other carpet beetle species.

It should be noted that modern insecticides such as DDT and Gammexane are only of limited value against carpet beetles. With these beetles the toxic action of DDT is extremely slow. Indeed, several investigators have recorded holding carpet beetle larvae alive in containers in which they were in direct contact with DDT powder for several weeks before they eventually died. Thus, although DDT is valuable for protection against carpet beetle attack, it could not be used effectively to obtain rapid reduction of an infestation. Gammexane is reported to be extremely effective as a killing agent, but in its present form is not suitable for household use on account of the lasting effect of its unpleasant smell.

Practicable preventive and control measures against the Australian Carpet Beetle may be summarized as follows:—

(a) Protection of light fabrics and clothing:

Where carpet beetles may be present, it is of particular importance that all materials liable to injury should be frequently aired and if pos-

sible hung in the sunshine. When they have to be stored for prolonged periods they should be packed in several layers of paper, folded so as to be as nearly insect-proof as possible. Naphthalene and paradichlorobenzene are of particular value for the protection of clothing. Naphthalene has a more prolonged effect and can be used in trunks etc., at the rate of approximately 1 lb. per trunk. Paradichlorobenzene acts more quickly and hence is more useful in drawers etc., in which damage may already have been observed. Where it is practicable to do so, clothing or fabrics found to be infested may be dipped in hot water at a temperature of 140°F. or more. This is a simple and effective remedy which will kill all stages of carpet beetles.

(b) *Protection of carpets and floor-coverings:*

Jenkins (1944) recommends that carpets and other floor-coverings should be insect-proofed with sodium fluosilicate. A solution is prepared of one ounce of the powder to one gallon of water, and this is applied to the backs of carpets so as to obtain as deep a penetration as possible.

(c) *Prevention of breeding in floor cracks, etc.:*

When evidence of carpet beetle injury is observed, a first essential is to ensure against their continued breeding in floor cracks, around baseboards, in cupboard linings, wardrobes, drawers and down the backs of chesterfields and upholstered chairs. In this respect a vacuum cleaner should be used whenever and wherever possible. Jenkins has pointed out the value of turpentine as a contact insecticide which also leaves a repellent residue for some time. As it is liable to stain it cannot be used where it may injure fabrics, but is excellent for application to flooring and in similar positions. Probably DDT is now the most valuable protection against the development and continued breeding of carpet beetle infestations in these places. A five per cent spray may be applied beneath carpets, and also inside cupboards and wardrobes where it can be covered by paper. A 10 per cent DDT powder, applied with a hand duster, may also be used. These DDT preparations should give protection for a period of several months at least. In practice they should be applied during the summer months when the adult beetles are on the wing and, if oviposition is prevented, spraying or dusting should not then be necessary until the following season.

(d) *Small-scale household fumigation:*

Although it is generally neither necessary nor practicable to fumigate a whole house for the control of pests such as carpet beetles, infested clothing and materials can be readily fumigated in a sealed trunk or cabinet. A number of commercial fumigants are useful for this purpose, and of these chloropicrin, in any of the commercial preparations sold for soil fumigation, is one of the most satisfactory. It can be used in a sealed trunk or cabinet, applied on a piece of sacking at the rate of a half to one ounce for 24 cubic feet of space. The exposure time should be approximately 24 hours. This preparation is reasonably safe for small-scale application as it is not inflammable and is sufficiently unpleasant to prevent users from exposing themselves to dangerous concentrations. Carbon bisulphide has been very generally recommended for the small-scale fumigation of clothing, etc., but while it is effective and readily available, the dangers of its use cannot be over-emphasized. It is highly inflammable, should never be in proximity to any heat source whatever and must be used only out-of-doors.

ACKNOWLEDGMENTS

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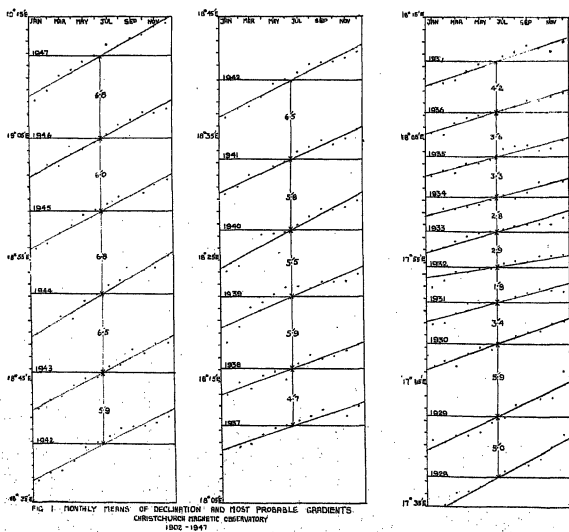
TRENDS IN MAGNETIC DECLINATION AT APIA AND CHRISTCHURCH

By J. W. BEAGLEY and J. M. BULLEN, Christchurch Geophysical
Observatory, Department of Scientific and Industrial Research

(Received for publication, 12 March 1949)

During 1946-47 a thorough investigation was made into the reliability of absolute magnetic instruments, absolute observations, base line values and instrumental constants at the Apia Observatory.

In order to check the consistency of the absolute observations of declination made there, the method of plotting monthly means as used by W. E. Scott (1) at Huancayo, Peru, was used—the period 1912-47 being treated in this way. During 1948 it was decided to extend this work to cover the monthly mean values of declination obtained by the Christchurch Magnetic Observatory from 1902 to 1947. Tables I and II of this paper contain the Christchurch and Apia values respectively. Where observed values were not available the most probable values were deduced by the principle of least squares from the series of monthly means for the respective years. Values were so obtained for the following months at Apia:—



June-December	..	..	1930
January	..	..	1934
June, July, August		..	1937

The yearly mean for these years is enclosed by brackets and the months affected indicated by an asterisk. For each year the most probable gradient was determined by means of least squares. These, as well as the monthly mean values for Christchurch, are plotted in Figs. 1 and 2.

Fig. 1 shows that generally the Christchurch plotted means follow the annual trend closely. Several years prior to 1913 give evidence of less precision as compared with later determinations of declination, and the monthly means for the year 1923 show a comparatively large amount of scatter. An investigation of the records for 1923 reveals that the base-line values computed from the declination observations were rather variable. Because of building operations near the Adie Magnetograph House at Christchurch the Eschenhagen curves obtained at Amberley were from this year used alone for determining the hourly values in all magnetic elements. 1923 also marked the change in measurement of ordinate from an instantaneous value at the Greenwich hour to the mean ordinate over the hour centred at the Greenwich hour. Absolute observations for standardization purposes still continued to be made at Christchurch. From these remarks it will be realized that there were sufficient factors which could contribute to the abnormal variation in the monthly means.

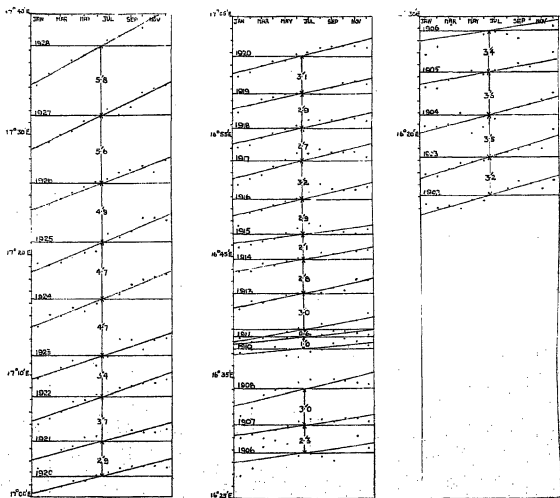


Fig. 2 illustrates trends at Apia graphically. As at Christchurch the plotted means follow the annual trend closely in the majority of years investigated. An investigation of composite graphs for the Apia and Christchurch data indicated that little or no seasonal variation existed at Apia while the seasonal variation at Christchurch was considerably less than one minute of arc.

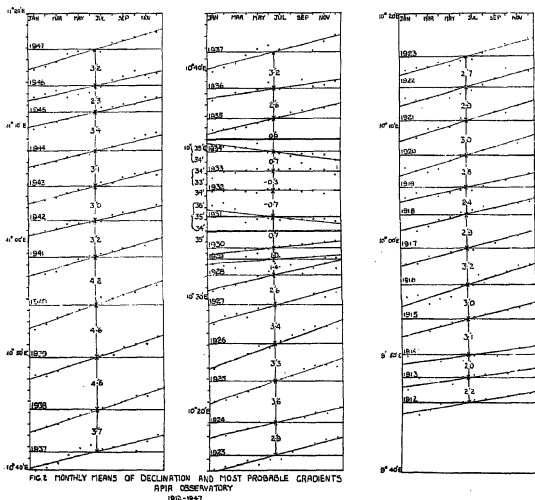


Fig. 1 and 2 clearly show differences in magnitude of the annual variation of declination and change in gradient of annual trend throughout the years.

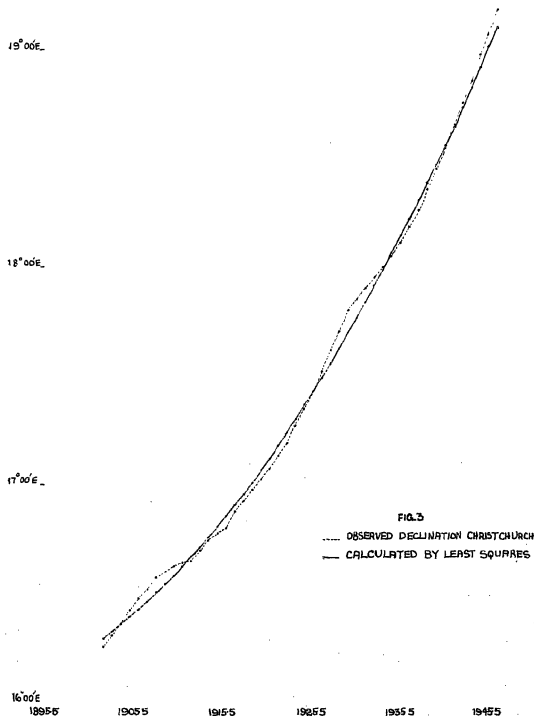
In order to investigate the annual or secular change at Christchurch, mean annual values were plotted as shown in Fig. 3.

It is well known that the secular change partakes largely of the character of the earth's main field. It is quite as difficult to account for as the earth's magnetism. There must be some deep-seated change within the earth but a satisfactory solution has yet to be offered.

Secular variation is a progressive change, the complexity of which is increased by superposed effects due to causes external to the main field. It was decided to find an adequate representation of what could be regarded as the main trend of declination at Christchurch so that any effects superposed on this trend might be investigated. Quite obviously in this case the straight line method as used by Scott for Huancayo would not give a true representation of the Christchurch data. Least squares methods were used to fit a curve to the observed values and the equation derived from this analysis was as follows:—

$$D_c = 16^{\circ}.2941 + 0^{\circ}.03026 (t-1902.5) + 0^{\circ}.0007085 (t-1902.5)^2 + 0.0000002477 (t-1902.5)^3$$

where 1902.5 is the initial epoch, and t any year after this epoch, easterly declination being reckoned positive. The curve thus calculated was found to give a fairly convincing fit.



Residuals were obtained by subtracting calculated values from observed values and these have been plotted as in Fig. 4. The residuals can be assumed to represent the external effects superposed on the main trend. There is a marked tendency towards a 22 year periodicity in these residuals which suggests the possibility of a sunspot relationship. For comparison purposes Zurich relative sunspot numbers are also plotted in the same figure.

TABLE I. MEAN MONTHLY DECLINATION (ALL DAYS) FOR CHRISTCHURCH MAGNETIC OBSERVATORY

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
1902	14.4	14.0	14.2	14.0	14.8	16° East Plus 14.7	15.1	15.7	16.3	16.1	15.7	16.4	15.1
1903	16.9	16.7	17.3	17.8	17.9	18.0	18.3	18.7	18.9	19.3	19.0	20.6	18.3
1904	20.9	20.8	21.0	22.0	20.3	20.8	21.5	22.2	22.4	22.7	23.1	23.6	21.8
1905	24.1	24.0	24.7	25.4	25.5	25.2	25.5	25.6	26.1	25.8	26.2	27.0	25.4
1906	26.8	27.5	29.3	29.8	29.5	28.5	28.7	28.5	28.2	29.8	30.2	29.2	28.8
1907	30.0	30.3	30.0	30.7	31.0	31.4	31.6	31.6	31.4	31.7	31.4	31.4	31.1
1908	31.8	32.5	33.6	34.0	34.1	34.6	34.8	35.1	34.9	34.8	34.6	34.5	34.1
1909													
1910	37.0	37.4	37.3	37.6	36.8	36.7	37.2	37.4	37.9	38.3	38.0	37.7	37.4
1911	37.6	38.0	38.0	38.1	38.3	38.3	38.6	38.6	38.9	38.9	38.7	38.6	38.4
1912	38.3	38.4	38.3	38.0	38.8	39.1	39.4	39.5	39.4	38.9	39.8	40.4	39.0
1913	40.7	41.4	41.2	41.5	41.8	42.0	42.0	42.1	42.5	42.3	43.2	43.1	42.0
1914	43.8	43.8	44.5	44.3	44.6	44.9	44.9	45.4	45.3	45.4	45.5	45.6	44.8
1915	45.8	46.0	46.3	46.5	47.0	47.4	47.8	47.6	47.2	47.1	46.9	47.3	46.9
1916	47.6	48.7	48.9	49.3	49.6	49.9	50.4	51.1	50.7	50.6	50.6	50.8	49.8
1917	51.0	51.5	51.8	52.5	53.0	53.6	53.6	54.0	53.7	53.7	53.7	53.3	53.0
1918	54.1	54.3	54.9	55.3	55.6	55.9	56.4	56.4	56.4	56.4	56.4	56.3	55.7
1919	57.0	57.6	58.1	58.3	58.5	58.6	58.5	58.6	59.1	59.5	59.6	59.4	58.6
1920	00.0	00.4	00.9	01.3	01.3	17° East Plus 01.8	02.0	02.4	02.5	02.5	02.5	02.4	01.7
1921	02.4	03.0	03.9	04.2	04.9	05.0	05.3	05.3	05.3	05.3	05.3	05.6	04.6
1922	06.0	06.5	07.0	07.9	08.0	08.5	08.7	09.0	09.2	09.4	09.4	09.7	08.3
1923	09.8	10.7	11.3	12.5	12.5	10.8	11.6	13.1	13.0	13.1	13.0	13.1	11.7
1924	14.1	15.1	15.0	15.7	15.4	16.0	16.6	16.8	17.6	18.0	18.2	18.4	16.4
1925	19.4	19.2	19.4	19.8	20.2	20.3	21.8	21.5	22.0	23.1	23.1	22.9	21.1
1926	23.4	24.2	24.7	25.2	25.7	26.1	26.4	26.9	27.1	27.4	28.9	27.9	26.0
1927	29.0	29.4	30.0	30.3	31.2	31.6	32.2	31.7	32.3	33.6	33.9	34.2	31.6
1928	34.1	35.1	36.1	36.2	36.6	37.1	37.9	38.2	38.4	38.9	39.9	40.9	37.4
*1929	40.4	40.2	40.8	40.8	41.1	41.9	42.3	43.4	43.6	43.8	43.9	46.1	42.4
1930	46.5	46.9	46.5	47.5	48.0	47.8	48.3	49.0	49.3	49.4	50.0	50.2	48.3
1931	49.9	50.0	50.8	51.6	51.7	51.8	51.8	52.2	52.5	52.8	52.7	52.6	51.7
1932	52.9	53.5	54.2	54.2	54.5	54.9	55.1	55.1	55.1	55.5	55.5	55.6	54.6
1933	55.9	56.2	56.7	57.1	57.4	57.5	57.7	58.0	58.1	58.2	58.1	58.7	57.5
1934	58.9	59.4	59.3	59.5	59.7	60.1	60.5	60.2	60.7	61.6	61.5	61.6	60.3
						18° East Plus							

TABLE 1. Continued

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
1935	02.0	02.5	02.3	03.1	03.1	03.4	04.3	04.5	04.6	04.1	04.3	05.0	03.6
1936	05.5	05.4	06.4	06.8	07.0	07.2	07.2	07.7	08.2	08.1	08.5	08.8	07.2
1937	09.5	09.6	09.9	10.6	11.2	11.4	11.8	12.2	12.7	12.5	12.2	13.0	11.4
1938	13.9	14.9	14.4	15.5	15.8	15.2	16.5	17.2	16.9	17.1	17.6	18.1	16.1
1939	18.2	19.5	21.1	21.5	22.2	22.8	22.8	22.7	23.2	23.2	23.3	23.9	22.0
1940	24.1	24.5	25.6	27.1	27.2	27.3	27.9	28.6	29.2	29.1	29.4	29.9	27.5
1941	30.4	31.0	32.0	32.1	32.7	33.1	33.9	34.3	34.8	34.5	35.0	35.8	33.3
1942	36.7	37.4	37.6	38.4	39.5	39.9	40.4	41.1	41.2	41.3	41.6	42.1	39.8
1943	42.7	43.4	43.7	44.6	45.2	45.3	46.2	46.3	47.6	47.3	48.1	48.2	45.7
1944	48.9	49.5	50.3	50.1	51.6	52.2	52.9	53.3	53.7	54.2	54.4	55.4	52.2
1945	55.9	56.3	57.2	57.8	58.7	59.1	59.6	60.2	60.3	60.5	61.2	61.6	59.0
						19° East Plus							
1946	02.1	02.8	02.7	03.7	04.1	04.7	05.4	06.2	06.6	07.2	07.1	07.5	05.0
1947	08.1	08.9	10.2	10.6	11.3	11.8	12.7	12.6	13.2	13.5	14.2	14.5	11.8

* From 1929 onwards Amberley Values are corrected to Christchurch Values.

TABLE II. MEAN MONTHLY DECLINATION (ALL DAYS) FOR APIA OBSERVATORY

Year.	Jan.	Feb.	Mar.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Mean.
1912	45.2	45.0	45.5	46.0	46.1	9° East Plus 46.2	46.3	46.4	46.5	46.7	46.8	46.9	46.1
1913	47.2	48.2	48.0	47.9	47.7	48.3	48.5	48.6	48.6	48.6	49.0	49.5	48.3
1914	50.1	50.7	49.5	49.7	49.6	49.7	50.2	50.3	50.2	50.3	50.9	50.9	50.3
1915	51.9	52.2	52.3	52.8	53.1	53.2	53.6	53.8	54.0	54.2	54.4	54.8	53.4
1916	55.3	55.5	54.7	55.2	55.4	56.3	56.4	56.6	57.2	57.6	58.1	58.2	56.4
1917	58.2	58.2	58.9	58.9	59.3	59.4	59.4	60.0	60.0	60.5	60.7	61.1	59.6
1918	01.2	01.1	01.5	02.1	02.3	10° East Plus 02.7	02.9	03.2	03.1	03.3	03.5	03.6	02.5
1919	04.0	04.4	04.1	04.1	04.4	04.6	04.6	05.0	05.4	05.5	06.3	06.1	04.9
1920	06.6	06.3	06.2	06.5	07.3	07.6	08.1	08.1	08.4	08.4	08.7	09.7	07.7
1921	08.5	09.2	10.0	10.1	10.1	10.9	11.2	11.6	11.5	11.4	12.0	12.4	10.7
1922	12.7	12.5	12.6	12.9	12.7	13.0	13.3	13.8	14.4	15.3	15.2	15.0	13.6
1923	15.1	15.3	15.4	15.8	15.5	15.9	16.0	16.6	17.3	17.4	17.7	17.9	16.3
1924	17.9	18.0	18.4	18.7	19.2	19.1	19.6	19.6	19.6	20.1	20.0	20.6	19.2
1925	21.1	21.1	21.4	21.9	22.3	22.8	23.0	23.3	23.9	24.1	24.2	24.1	22.8
1926	23.9	24.4	24.7	25.2	25.9	26.7	26.3	26.8	27.3	27.6	27.6	27.4	26.1
1927	27.8	28.5	28.7	28.4	29.2	29.3	29.5	30.1	30.6	30.5	30.3	30.6	29.5
1928	30.7	30.9	31.2	31.5	32.0	32.4	32.8	33.0	32.2	32.7	33.1	32.7	32.1
1929	33.1	32.9	32.7	33.7	34.0	33.5	33.7	34.0	34.0	33.7	33.6	33.6	33.5
1930	34.0	34.0	34.1	34.4	34.4	34.1	34.6*	34.7*	34.8*	34.9*	35.0*	35.1*	(34.5)
1931	36.2	36.4	35.8	34.7	35.0	35.0	34.9	35.0	35.0	35.0	35.0	34.8	35.2
1932	34.4	34.4	34.6	34.4	34.3	34.6	34.6	34.6	34.4	34.5	34.2	34.5	34.2
1933	33.6	34.1	34.0	34.2	34.4	34.3	34.3	34.4	34.9	34.4	34.3	33.9	34.2
1934	35.7*	35.3	35.2	35.2	35.6	34.9	34.7	34.5	34.7	34.7	34.6	34.2	(34.6)
1935	34.8	34.8	34.8	35.0	35.4	35.6	35.9	36.3	36.5	36.6	36.7	37.0	35.8
1936	37.4	37.7	38.0	38.0	38.3	38.9	38.3	38.6	38.6	38.7	38.7	39.0	38.8
1937	39.9	40.2	40.6	41.3	41.9	42.2	41.8*	42.0*	42.2*	41.7	42.5	43.1	(41.6)
1938	43.4	43.8	44.0	44.5	44.8	45.2	45.5	45.7	46.0	46.5	46.5	47.1	45.3
1939	48.3	48.2	48.7	49.1	49.4	49.9	50.1	50.1	50.8	51.1	51.1	51.7	49.9
1940	52.3	52.8	53.4	53.7	54.1	54.5	55.2	55.1	55.4	55.6	56.1	56.2	54.5
1941	57.1	57.2	57.4	58.0	58.5	58.8	59.0	59.2	59.5	59.7	59.7	60.3	58.7
1942	00.7	01.0	01.3	01.6	01.6	01.7	01.8	02.4	02.6	02.6	02.8	03.3	01.9
1943	03.5	03.7	03.9	04.3	04.6	04.9	05.3	05.2	05.7	06.0	06.1	05.9	04.9
1944	06.6	06.9	07.1	07.5	07.6	07.7	08.0	08.4	08.1	09.1	09.4	09.6	08.0
1945	09.6	10.1	10.6	10.8	11.1	11.4	11.8	11.9	12.1	12.1	12.7	11.4	12.7
1946	12.7	13.0	13.8	12.7	12.9	13.1	13.6	14.2	14.5	18.0	14.6	14.7	13.7
1947	15.1	15.4	15.8	16.5	16.7	16.9	16.7	17.5	17.7	18.0	18.2	18.4	16.9

* Most probable values deduced by principle of least squares from series of monthly means for respective year.

It was found that the maxima in the Christchurch residual curve at 1907.5 and 1930.5 lagged two years behind the sunspot maxima at 1905.5 and 1928.5 which is in agreement with the findings of other investigators that magnetic activity lagged behind the sunspot maximum. The minima, however, do not show any absolute agreement on this point. That at 1921.5 shows a lag of four years behind the sunspot maximum at 1917.5 while the minimum at 1938.5 lags only one year behind the corresponding sunspot maximum at 1937.5.

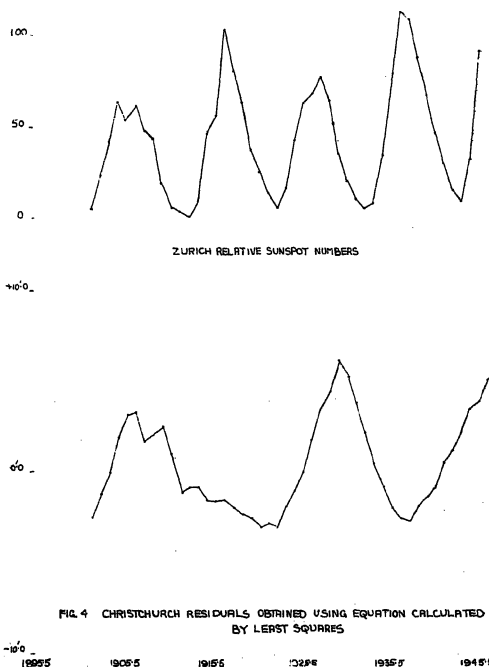


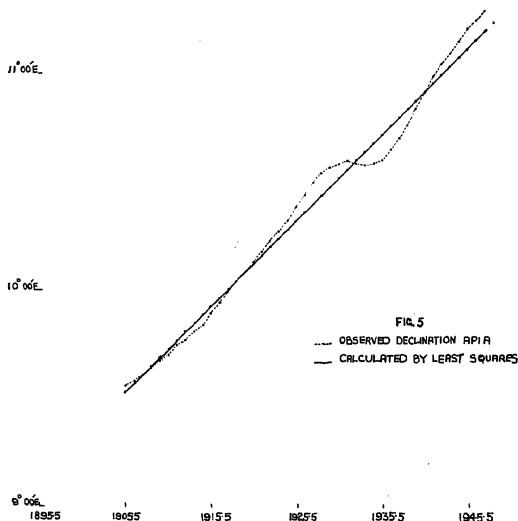
FIG. 4. CHRISTCHURCH RESIDUALS OBTAINED USING EQUATION CALCULATED BY LEAST SQUARES

Mean annual values 1905-1947 for Apia were next plotted as in Fig. 5. In the case of Apia it was more difficult to decide upon the best means of representing the main trend. Finally it was considered that a straight line fitted by least squares methods would give a fair indication of the main trend although it would not be entirely satisfactory in the years between 1925.5 and 1935.5.

The equation obtained was as follows:—

$$D_r = 9^{\circ}.5315 + 0^{\circ}.0392 (t-1905.5)$$

t representing any year after the epoch 1905.5. Calculated values have been plotted in a manner similar to the Christchurch data. See Fig. 5.



In Fig. 6 are plotted the differences between the observed values and values calculated by using this equation. The period covered was shorter than that for Christchurch though of sufficient length to indicate also a tendency towards a 22 year periodicity. When times of maxima and minima of the Apia residual curve were compared with Zurich relative sunspot numbers the agreement was not so marked as with Christchurch but sufficiently so to suggest a relationship with the Zurich relative sunspot curve and the Christchurch residual curve.

A maximum at 1928.5 coincided with the Zurich sunspot maximum while the minima at 1914.5 and 1935.5 occurred three years and two years respectively earlier than the corresponding sunspot maximums at 1917.5 and 1937.5. This lack of agreement in lag as compared with Christchurch can be explained by the fact that the straight line representation as used for Apia's main trend is not as true as the curved fit obtained for Christchurch. This statement is supported by work which was done by treating in a similar fashion the declination data at the following observatories: Honolulu, Pilar, Alibag.

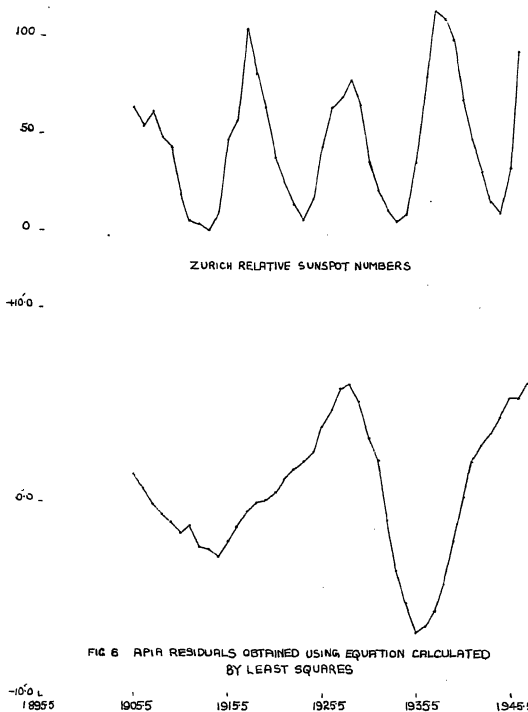
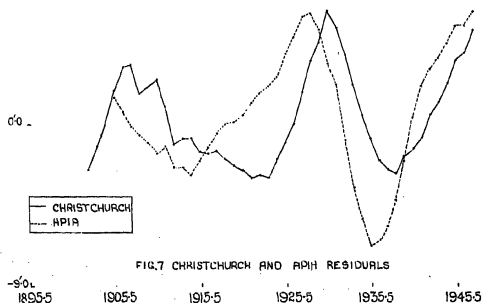
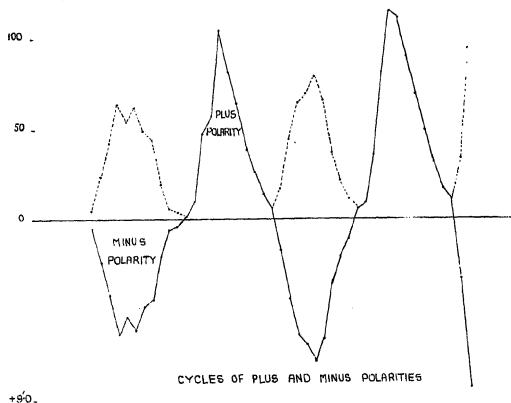


FIG 6 APIA RESIDUALS OBTAINED USING EQUATION CALCULATED BY LEAST SQUARES

In all cases a periodicity of the order of 22 years in the residuals was found but the times of maxima and minima depended on the degree of the empirical equation representing the progressive trend in declination.

In Fig. 7 the Apia and Christchurch residuals are compared with the cycles of plus and minus polarities of sunspots. This gives a much better picture of the degree of relationship existing between these quantities.

The size of the sample under investigation plays an important part in the determination of the true main trend curve. Glover (2) in discussing the Apia data for the period 1905 to 1929 obtained a theoretical second degree curve for the trend which would have been a bad fit for



the data of the year 1931 onwards. In order to determine the law which governs the effects superposed on the main trend it would seem that a much longer series of data is needed if this method of attack is to be utilized. However, the work done in this paper supports the view that secular variations show small-order dependence in their progress on the sunspot cycle.

REFERENCES

- (1) SCOTT, W. E. (March, 1943): *Terr. Mag.* p. 45.
- (2) GLOVER, P. W. (March, 1935): *Terr. Mag.* p. 61.

FUSED AND BAKED SEDIMENTS ASSOCIATED WITH BASALTIC LAVAS AT ELLERSLIE, AUCKLAND, NEW ZEALAND

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Summary

The occurrence of a sheet of baked sediments intercalated between two flows of basaltic lava is described and its mode of emplacement is discussed. A brief account is given of the petrographic characters of the vitrified and crystallized rocks produced.

DESCRIPTION

NATURAL brick, formed by the baking of sedimentary material by heat of volcanic rocks, is found in many localities throughout the Auckland volcanic fields in association both with the pyroclastic rocks of the scoria mounds and with the basalt of the lava flows that emanate from them. The occurrence herein described is unusual in the relationship shown between the lavas and the brick, and in certain physical characteristics of much of its material.



FIG. 1.—South-east face of Wilson and Rothery's Quarry, showing sheet of baked sediments intercalated between lava flows.

The brick is exposed in Wilson and Rothery's Quarry, Ferndale Road, Ellerslie, where an excavation six chains long by three chains wide has been made in the basalt of lava flows from Mount Wellington. It appears to rise from the north-east corner of the quarry (Fig. 2), as a dyke-like body of red brick with well-developed horizontal prismatic jointing produced as a result of shrinkage following drying out during the baking process; the shrinkage prisms have a width of approximately one inch and are at this point much coarser than they are elsewhere in the exposure. At floor level the mass has a width of three feet and rises almost vertically to a height of five feet above the floor where it divides into two branches each about 18 inches thick and diverging from one another at an angle of about 120° . At a height of 10 feet above the floor of the pit and 20 feet below the top of the face they become substantially horizontal; this horizontality of the outcrop is maintained

round all the walls of the pit. The northern branch varies considerably in thickness and opens out into a pocket 15 feet long and four feet thick before it is obscured by the buildings of the crusher plant; where it again becomes evident on the other side of the crusher it has thinned out once more and finally peters out completely at a point about four chains distant from the north-east corner of the pit where it would appear to have reached the surface of the covering flow in a surface depression. It is noteworthy that the material of which this portion of the sheet is composed is earthy and incoherent near the base of the sheet but close to the over-lying basalt it is compact and brick-like and shows fine prismatic jointing. Moreover, there is, near its northern end, a considerable proportion of slaggy and scoriaceous basalt—some fragments having natural brick fused to their surface—mixed with the fine-grained reddish sediment.



FIG. 2.—North-east corner of quarry pit showing sediments rising from floor to form a sub-horizontal sheet.

The other branch diverging from the rising mass in the north-east corner, passes across the eastern face of the pit for a distance of three chains and can thence be traced for a further five chains in the southern wall. Like the outcrop just described, this too, varies somewhat in thickness, for although the average thickness is approximately 18 in. this increases in places to three feet or more. Its material is much more thoroughly baked than is that of the northern portion of the sheet and in consequence the columnar structure is more highly developed and the



FIG. 3.—Pocket of baked sediment showing shrinkage prisms. The upper and lower glassy selvages are apparent.

prismatic cleavage cracks pass from surface to surface right through the sill-like mass; the columns are perpendicular to the upper and lower contacts of the sediment in the thin parts of the sheet but have radial dispositions in the pockets (Fig. 3). An outstanding feature is that glassy selvages have been formed on both the upper and lower surfaces of the brick which is thus fused to the enclosing basalt above and below. In some places where this effect is most noticeable, the selvedge is about a quarter of an inch thick and the fused glass which has penetrated the narrow shrinkage cracks to a distance of several inches has frequently the form of thin-walled bubbles in cavities between the prisms (Fig. 4). Elsewhere masses of natural porcelain have been produced, sometimes at the contact of sediment and basalt and sometimes as frothed up vesicular masses with coralloid appearance.

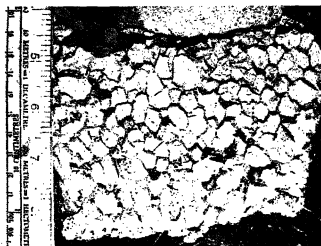


FIG. 4.—Baked sediment, showing fine polygonal shrinkage prisms, fused to basalt by a glassy selvedge. Note the dark glass which has penetrated the shrinkage cracks and formed thin-walled bubbles.

The basalt underlying the part of the "sill" under description has been much broken by shearing, and, in fact, is so shattered that it practically crumbles when struck with a hammer. This would appear to be due to movement within the flow at a stage when its material was not completely solidified; this is substantiated by the very flaggy nature of the rock in the eastern face where flags produced by shearing have been curled over and have striae on their surfaces produced by blocks sliding one over another. Several of these flags have natural brick adhering to their surfaces and others show selvages embossed with the distinctive polygonal pattern developed in the brick (Fig. 5). It would seem, therefore, that the underlying lava was hot when it came in contact with the sediment, now present as brick, and that movement occurred in it after baking.

Near the south-east corner of the quarry the structure of the "sill" becomes more confused and it is seen to divide and pass round small horsts of the underlying basalt; in one case, for example, an upper sheet seven inches thick is separated from a lower sheet, three inches thick, by a mass of basalt four inches in thickness. All the surfaces between the brick and basalt are here marked by thick glassy selvages by which the two rocks are fused together. Near at hand, as elsewhere in the

exposure, thin vertical offshoots of the "sill" penetrate several feet downwards into the underlying basalt and show finely-developed shrinkage prisms. Such features indicate that the sediment was in a highly plastic state when it was emplaced.



FIG. 5.—Basalt underlying the baked rock with curved flags produced by shearing and striated by slickensiding and with natural brick fused to their surfaces.

In the exposure along the southern face the baked brick is intermixed with much scoriaceous slag and with blocks of scoria covered with glassy natural porcelain, and, as a result, the sill loses its striking bright-red colour and its beautiful prismatic structure. There are some pockets in which the sediment has the appearance of burnt brick, being dark brown in colour, closer in texture with macroscopic crystals of haematite and formed of closely-spaced prisms only a quarter of an inch wide. On the western end of the wall there are pockets of incoherent red earthy sediment but volcanic debris becomes an increasingly more important constituent of the filling so that when the sheet finally rises vertically to make contact with the surface of the flow it is almost wholly constituted of scoriaceous fragments.

Quarrymen report that a blow was encountered on the floor of the pit near the northern wall which was filled to within five feet of the roof and from which 250 yards of red, largely-earthly baked sediment was removed.

MODE OF EMPLACEMENT

It is suggested that the sheet of natural brick was formed from sediment which had accumulated in tiny lakes or swampy hollows on the pre-volcanic surface or on the surface of previously extruded lavas. The former would appear to be the more likely, as silts are known to underlie the lavas in nearby areas and baked silts are found at other places in the lavas of the Mount Wellington field. At Winston's quarry, one mile north of the present occurrence, baked silts are found in which the imprints and moulds of the leaves of rushes are present. It would be unlikely that sufficient time intervened between the emission of successive lava sheets from Mount Wellington to permit such vegetation to become established. It is suggested that the lava flood advanced by the outflowing of lava tongues from its front and that three of the tongues converged near the site of the quarry. One of these tongues forms the lower part of the northern face and was substantially cool before the arrival of the other sheets. A second tongue "toed up" the sediment

against the flanks of the earlier one whilst the third following rapidly upon it overtook and overwhelmed the squeezed-up sediments and spread them into a thin sheet between the flows. The sediment, sandwiched between the masses of hot rock on the south, became more thoroughly baked than it did on the northern side where there was hot rock on the top only.

PETROGRAPHY

Macroscopically the basalt of the upper and lower flows is similar to that found commonly throughout the Auckland Isthmus and examination in thin section shows that they are indeed olivine basalts typical of that area with abundant large phenocrysts of olivine and augite together with laths of plagioclase set in a groundmass of feldspar and pyroxene, and having iron ore scattered liberally throughout (Fig. 6). The groundmass is glassy near the surface and around vesicles.

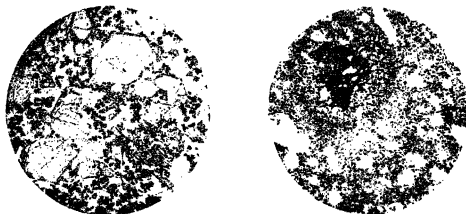


FIG. 6.—Photomicrograph of olivine basalt from flow underlying the natural brick.

FIG. 7.—Haematite grain in baked sediment surrounded by a halo of haematite rods. The base of the rock is largely isotropic but feldspar appears fairly freely in tiny grains and there is abundant scattered opaque material (? haematite). The white patches are vesicles. $\times 33$.

Thin sections were made of various types of baked material found in the sheet between the lava flows. The bulk of the material is a compact, rather vesicular rock, very fine in grain and coloured red by scattered tiny rod-like aggregates of haematite. A few granular crystals of plagioclase are distributed throughout the sediment but the writer was unable to determine the mineralogical character of the very fine-grained material which constitutes the main mass of the rock.

Near the contact the sediment has been almost completely feldsparitized during baking and is almost wholly constituted of granular and irregular grains of feldspar with a few scattered laths of the same mineral. It, too, is vesicular, and its vesicles are often lined with small rods of haematite. There are rare crystals of greenish fresh pyroxene and others where the pyroxene appears to have been replaced by haematite. The photograph (Fig. 7), shows that this haematite has been formed, at least in part, by the alteration of fragments of basalt (or of material derived from the basalt) included in the sediment.

Sections of basalt from near its contact with the brick show that it, too, has suffered alteration as a result of interaction of the materials of the sediment and of the lava at their interface. The glassy ground-

mass of the basalt has been rendered practically opaque owing to the presence of granules and rod-aggregates of iron oxide (? magnetite) (Fig. 8), but a more striking change has taken place in the olivine phenocrysts, and to a less extent in those of pyroxene, which have suffered change to magnetite. It is clear that this change has resulted from reaction as a complete succession of forms may be traced from those in which the olivine is fresh but permeated with arborescent aggregates of iron oxide with their main rods arranged perpendicular to the periphery of the crystal and penetrating about half way to its centre.



FIG. 8.—Glassy basalt opaque with iron ores, including haematite, with an inclusion of fairly evenly feldspathized sediment. The dark needles in the sediment are pale green pyroxene. To the right of the inclusion is a large phenocryst of olivine which has been almost completely converted to magnetite. Several crystals of augite may also be seen in the basalt. Ordinary light. $\times 33$.

FIG. 9.—Same glassy basalt as in Fig. 8 showing the development of magnetite in olivine phenocrysts. $\times 33$.

Intermediate forms show the rods to be present over the whole of the area of the section of the olivine but much fresh olivine is apparent. In the final stages the parentage of the iron ore is recognizable only in the characteristic shapes of its aggregates. (Figs. 9 and 10.)

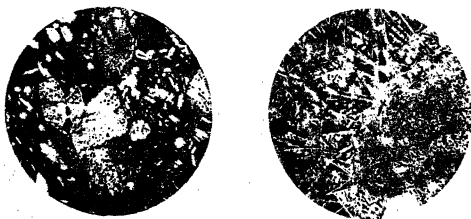


FIG. 10.—Phenocrysts of olivine in glassy basalt near contact with sediment showing alteration to magnetite. Under high power the magnetite rods often appear like strings of tiny beads. $\times 33$.

FIG. 11.—An aggregate of coarse grains of brownish augite surrounded by a halo of radiating plumose needles of feldspar and enclosed within colourless vitrified sediment (appears white in photograph). The small prismatic crystals in the glass are olive-green pyroxene, small granular crystals of which also make up the dark linear aggregates. $\times 33$.

Bartrum (1942) has drawn attention to the unusual development of iron ore in the olivine of a "chance boulder" from Otahuhu which was not traceable to its parent quarry and of rock from the summit cone of Rangitoto, and remarks that "after examination of hundreds of thin sections of olivine basalts" he could recall no other rocks showing the same characteristics. He describes the iron ore as occurring as "irregular clots which are often aggregated into rod-like or string-like bodies" and notes that the margins of the olivine (near forsterite) phenocrysts are bordered by a definite reaction rim of magnetite. His description, and the photomicrograph which illustrates his paper, show a marked similarity between the rocks he describes and those found in the basalt near the contact in the present example.

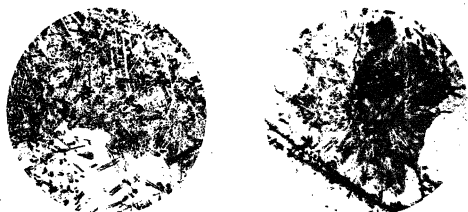


FIG. 12.—Yellow glassy and crystallized sediment in contact with basalt. The lower portion is a clear colourless glass studded with acicular crystals of greenish pyroxene and rarer fine needles of feldspar. The darker area above is rich in fine, long and "feathered" needles of feldspar together with the same pyroxene. Above the field of view the rock is more granular. $\times 33$.

FIG. 13.—Finely crystallized feldspathized sediment below bordered by a zone composed of long "feathered" radiating needles of feldspar with pyroxene (dark in photo) and some glass. Just above, but outside the field of the photograph this deep-coloured zone passes into colourless glass as in Fig. 11. $\times 33$.

A thin layer of glass is frequently present between the feldspathized sediment and the basalt: it is highly vesicular and often forms the skin of thin bubbles and penetrates the brick along shrinkage cracks for a distance of several inches. It is generally dark and almost opaque in hand specimens but in a few instances clear greenish yellow glass was observed; sometimes the glaze has the appearance of rather dull greyish-yellow porcelain. Thin sections made at the interface through this region of natural glaze showed the following definite recognizable zones:—

(a) Basalt with large phenocrysts of olivine almost entirely replaced by magnetite and with a glassy groundmass which is almost opaque as a result of the formation of fine mineral grains.

(b) A transparent and almost colourless glass with long yellowish-green needles of pyroxene and rarer acicular crystals of feldspar. From close contact with the basalt "spherulite-like" radiating masses of feldspar needles are plumose in form being "feathered-out" at the ends by smaller diverging needles.

(c) Further from the basalt, the glass appears to be largely devitrified and is almost wholly made up of feldspar needles in radiating and interlocking masses.

(d) The material of the zones so far described has comparatively few vesicles but in the next zone of interlocking granular feldspar with rare needles of pyroxene there are abundant vesicles lined with small rods of haematite; granules of iron ore are freely scattered throughout the rock.

In one section the outermost portion of the basalt is coloured red with haematite and small squat crystals of pyroxene are particularly abundant along the actual interface between glass and basalt, and in others tiny pyroxenes have developed around the vesicles. In one of these latter, shown in the photomicrograph (Fig. 14), an ovoid mass of interlocking grains of feldspar is ringed by a corona of yellowish pyroxene and small crystals of magnetite; it would appear to represent a small fragment of sediment which had been caught up in the glass.

From the debris between the two flows in the south wall there was collected brick burnt to a dark brown colour which was more highly indurated than the normal red brick. In thin section it is seen to be constituted of plagioclase, mostly in irregular grains but showing some typical laths. It is highly vesicular and the vesicles are lined with haematite (Fig. 15). Some rare crystals of green augite are present, and elsewhere there are pyroxene crystals in process of alteration to haematite. Pyroxene and small needles of haematite, apparently derived from earlier pyroxene, form haloes surrounding several larger haematite masses, which appear to have been formed from the alteration of inclusions of glassy basaltic fragments.



FIG. 14.—Fragment of small tongue of opaque glassy basalt in recrystallized sediment with, on right, an ovoid mass ringed by a corona of yellowish pyroxene. Inside the ring laths of feldspar with irregular crystals of yellowish pyroxene, some stained with haematite, and a little magnetite in octahedra. At bottom the finely-crystallized sediment passes suddenly into the glass with long needles of feldspar. $\times 33$.

FIG. 15.—Vesiculated sediment from above the lower basalt. The white areas are vesicles ringed with pale greenish pyroxene and opaque iron ore. The rock is finely-granular feldspar with scattered grains of iron ore and the dark triangular patch is a fragment of altered basalt. $\times 33$.

Another interesting rock appears macroscopically to resemble a frothed up basaltic lava for it is blue-black and well vesiculated. It is found in slaggy lumps with hummocky surfaces lustrous with a felt of small haematite crystals (Fig. 16). Through the courtesy of Mr. Buckley,



FIG. 16.—Slaggy vesicular sediment. The lustrous dark surfaces are coated with haematite grains.

Amalgamated Brick and Pipe Co., Ltd., New Lynn, the writer has examined specimens of natural brick from Kopuku, near Pokeno, which has been formed by the baking of clay as the result of combustion of an underlying coal bed. The clay is associated with gravelly material and while the clay has been baked to a pale pink brick the coarser material (Mr. Buckley states) has frothed up into a lava-like rock similar in hand specimen to the particular material from Ellerslie under description. Mr. Buckley has produced similar material in the kilns at New Lynn by baking conglomerate from Kopuku.*

* Personal communication. The writer has since visited Kopuku and found that the fused rocks have been formed by the alteration of greywacke pebbles in a conglomerate lying some fifteen feet above the coal.

In thin section the slaggy baked sediment from Ellerslie appears rather granular in texture with some of the grains of feldspar, the predominating mineral, showing overgrowth. Magnetite is abundant in small grains and aggregates which are at times demonstrably derived from the alteration of olivine, for remnants of olivine may be recognized in the centre of some of the iron ore masses. Small acicular crystals of pale green pyroxene are present and appear to be most abundant, together with rods of iron ore in the rock surrounding the very numerous vesicles that crowd the rock.

In the more slaggy parts of the sheet pale yellowish natural porcelain is found both fused to blocks of basalt and as large lumps in the filling. In hand specimen this material has rather a corralloid nature for while the rock is itself comparatively dense the mass as a whole is considerably frothed-up. The surfaces are smooth and glazed and the rock which is almost opaque and has numerous tiny vesicles is little more than the partitions between large coalescing vesicles (Fig. 17). In thin section this rock resembles the yellowish glass already described.

The writer has found it difficult to locate much information in the literature to which he has access as to work done on such altered sediments. Harker (1932) makes reference (p. 27) to the vitrification of argillaceous or arenaceous sediments for a few inches from their contact with a dyke or sill as being due to the "sufficient supply of solvent, viz. water," from a magmatic source so that the rock has been bodily vitrified.

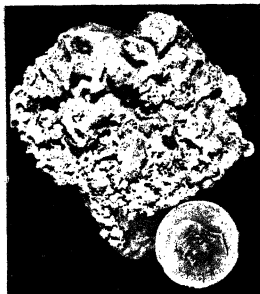


FIG. 17.—Lava-like fused sediment.



FIG. 18.—Creamy yellow porcellanous fused sediment. Note the tiny vesicles in the dense glassy rock.

The effect extends only a few inches from the contact and is of rare occurrence for it requires favourable conditions. "The high initial temperature demanded is realised only in basic or ultrabasic intrusions, and magmas of this kind are those least rich in water." In the present case it is presumed that adequate water would be present in the plastic sediment from which the fused sediments were produced. The same author (p. 70) states that inclusions of sandstone in basalt are often partly vitrified and numerous occurrences have been described under the name "buchite"—a term (p. 27 footnote) which is sometimes used to describe the vitrified product of any sediment or more specifically vitrified sandstone.

Particular interest in the present examples attaches to the interaction between the basalt and the sediment resulting in the development of iron ores from the ferromagnesian minerals.

ACKNOWLEDGMENT

It was intended originally that this paper should appear under the joint authorship of the writer and the late Professor J. A. Bartrum who prepared most of the thin sections and made the photomicrographs. Unfortunately at the time of his death he had made no written notes on the results of his examination of the rocks or of any conclusions that he had reached. The present writer is conscious of his inadequacy to discuss critically the petrogenic issues involved but has felt it desirable, nevertheless, to place on record such description of the occurrence as he was able.

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EARTHQUAKES IN NEW ZEALAND DURING THE YEAR
1948

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(Received for publication, 11 May 1949)

Particulars of all earthquakes in the New Zealand region during the year 1948, whose epicentres were determined, are tabulated below. The approximate epicentres of these earthquakes are shown on the accompanying map, with the exception of ten shocks, whose epicentres were beyond the boundary of the map. Approximate isoseismals of two of the principal earthquakes during the year are shown on inset maps.

Origin Time. (G.M.T.)*			Epicentre :		Max. Felt Inten- sity. (M-M).	Origin Time. (G.M.T.)*			Epicentre :		Max. Felt Inten- sity. (M-M).
1948	h.	m.	Lat. S (deg.)	Long. E (deg.)		1948	h.	m.	Lat. S (deg.)	Long. E (deg.)	
Jan.						Mar.					
1	06	41.8	38.3	175.8	---	1	22	56.5	38.9	176.0	II
1	16	58.4	41.8	173.0	---	1	23	26.1	38.9	176.0	II
2	05	46.2	38.3	175.8	---	2	01	13.1	38.9	176.0	III
2	06	31.9	38.6	175.9	---	2	04	34.5	38.9	176.0	II
4	08	22.9	41.1	173.2	V	2	10	12.3	38.9	176.0	IV
5	08	11.7	38.0	177.8	III	2	11	16.3	39.0	175.3	IV
7	21	27.5	38.8	179.0	II	2	19	45ca	38.9	176.0	I
9	04	11.9	40.2	175.0	III	3	09	38.7	39.9	175.3	III
9	08	34.8	38.1	178.6	IV	5	02	34.0	41.3	175.1	I
12	08	49.0	40.4	173.0	---	5	04	35.5	43.5	171.1	---
13	13	27ca	45.0	168.7	I	5	08	43.2	38.7	178.2	II
13	13	32ca	45.0	168.7	I	10	09	21.0	38.4	175.8	V
15	05	01.7	40.4	175.0	VI	10	17	31ca	40.9	175.8	II
19	17	54.9	40.2	173.2	---	10	16	21.2	40.4	172.8	---
20	03	07.7	39.4	176.8	---	15	14	04.5	40.1	174.7	II
20	09	44+	34.5	177.7W	I	23	02	45.0	40.4	176.4	I
24	08	00.5	39.0S	175.9	---	24	13	23.3	40.1	174.9	IV
25	11	42.7	40.2	175.0	I	24	15	50ca	39.3	177.9	III
25	14	56.7	40.1	172.9	---	31	17	40.7	33	178W	---
25	15	30ca	36.3	174.1	III?	Apr.					
26	11	54.0	38.8	175.9	---	8	05	57.0	40.1	174.8	III
27	22	52.8	41.5	173.8	II	18	09	05.7	40.6	175.3	II
Feb.						18	19	34.1	40.0	176.1	I
1	11	05.1	40.7	175.4	II	18	23	39.5	41.4	172.2	III
1	16	07.0	39.7	177.2	---	20	04	29.4	32.0	180.0	---
4	11	45.6	40.9	175.7	II	22	18	19ca	43.0	171.4	II
4	18	59.1	41.0	173.6	V	24	08	20.1	42.2	177.3	---
5	01	09.7	38.6	176.1	---	25	19	04.5	41.6	172.2	III
5	05	30.6	38.2	176.8	---	May					
5	05	30ca	40.1	175.0	II	20	14	59.5	39.3	177.9	---
5	09	45.2	38.4	175.8	---	22	18	57.6	42.5	172.9	VI+
5	23	21.8	39.6	176.4	---	22	19	21.5	42.5	172.9	VIII
6	03	25.5	23.0	179.5W	---	22	19	29.5	42.5	172.9	II
9	11	13.9	41.4	175.0	IV	22	19	36.3	42.5	172.9	V+
12	17	49.7	40.0	175.2	II	22	19	53.8	42.5	172.9	IV+
18	00	17.6	38.3	177.8	IV	22	20	01.4	42.5	172.9	IV+
18	03	57.8	43.5	173.3	III	22	21	22.0	42.5	172.9	IV+
24	21	37.6	39.6	175.2	---	22	22	00.0	42.5	172.9	---
27	00	38ca	45.9	167.9	III	22	22	55ca	46.4	168.4	II
27	09	49.7	42.1	173.3	III	22	23	28.6	42.5	172.9	---
29	14	10.8	43.0	171.4	IV	22	23	59.0	42.5	172.9	---



Origin Time. (G.M.T.)*			Epicentre :		Max. Felt Inten- sity. (M-M).	Origin Time. (G.M.T.)*			Epicentre :		Max. Felt Inten- sity. (M-M).
1948	h.	m.	Lat. S (deg.)	Long. E (deg.)		1948	h.	m.	Lat. S (deg.)	Long. E (deg.)	
May						Aug.					
23	05	40.4	42.5	172.9	—	16	20	20.8	37.7	178.1	—
23	18	56.5	42.7	173.1	—	19	11	44.5	38.8	178.4	II
24	02	17.2	42.5	173.0	—	19	12	25.9	38.8	178.4	II
24	12	09.8	37.5	176.8	—	20	08	14.9	40.3	175.2	III
25	17	24.6	37.4	177.7	V	20	16	38.3	41.7	171.9	—
26	01	25.0	42.5	172.9	IV	20	22	37ca	32	177W	—
28	20	18.6	39.1	178.5	III	21	15	37.3	39.3	176.7	III
28	22	16.0	39.3	178.4	—	23	00	30.6	42.4	172.8	—
30	20	13.8	41.4	174.8	II	28	07	15ca	43.3	171.6	II
Jun.						29	04	58.4	41.2	174.8	IV
1	08	05.0	41.1	175.1	II	30	11	52.5	42.4	173.0	—
2	18	31.4	42.4	172.7	—	30	19	34.7	38.7	177.8	—
2	22	53.4	42.5	173.0	—	31	03	53.3	41.3	174.5	II
3	03	57.3	38.4	176.0	—	31	23	07.5	35	176W	—
7	07	17.6	37.3	178.0	—	Sep.					
7	18	05.9	37.2	177.5	I	2	09	54.3	41.9	172.4	—
9	06	41.3	42.4	172.7	—	4	08	20.4	39.8	177.2	—
10	02	48.9	37.3	177.1	—	4	18	12.6	42.5	173.1	—
13	08	08.6	42.4	172.9	—	5	07	04.1	40.0	173.1	—
14	11	08.0	42.2	171.9	?	5	23	14.9	41.2	172.9	—
14	14	31.7	42.2	173.2	—	6	00	34.6	43.4	171.4	IV
16	12	00.8	39.0	174.1	I	6	00	39.0	38.1	177.4	V
16	23	51.0	42.3	172.7	—	7	21	47.1	41.3	174.6	I
19	01	15.4	39.2	177.8	—	9	16	29.3	40.1	175.3	IV
19	06	18.6	43.2	169.2	VI	10	03	40.0	40.1	175.3	III
19	06	57.1	43.1	169.2	IV	11	17	16.4	40.1	175.3	V
19	07	05.6	43.2	169.1	VI	14	04	59.9	39.2	177.3	—
19	08	14.8	43.2	169.2	III	14	12	10.2	42.5	173.2	—
20	20	55.4	38.8	176.1	—	15	23	24.4	37.8	177.4	—
21	20	05.4	41.2	175.0	IV	16	10	30.0	38.8	176.1	—
22	21	31.8	40.9	175.3	IV	16	12	48.6	40.3	177.0	—
29	09	14.0	43.3	171.8	III	16	14	01.1	39.7	176.7	—
30	19	26.8	38.6	178.9	IV	17	08	34ca	40.1	175.3	II
July						29	18	03.0	41.2	174.5	II
1	18	37.4	39.7	176.7	—	Oct.					
3	19	13.8	42.1	172.4	—	4	16	28.6	38.2	176.8	—
3	21	10.4	38.1	176.7	—	5	03	59.6	41.4	174.1	III
4	14	13.2	40.2	175.5	IV	5	08	47ca	40.9	172.1	IV
11	08	04.9	42.4	172.7	—	8	20	23.6	39.8	174.9	—
11	19	24.6	38.6	178.9	III	8	21	21.0	42.9	172.8	—
12	00	24.2	42.2	172.6	IV	9	19	11.0	45.3	168	III
12	07	46.6	45.8	167.6	V	11	02	04.7	39.3	175.3	—
13	11	37.2	39.3	176.2	—	12	17	52.6	40.2	175.0	—
14	03	19.5	45.8	167.6	IV	13	18	16.8	38.0	177.1	III
14	10	48.4	45.8	167.6	VI	13	19	34.1	38.0	177.1	IV?
14	14	20ca	45.8	167.6	I	16	17	46.7	40.4	174.2	III
16	16	34.7	38.6	175.2	III	20	06	02.4	40.8	173.9	—
17	10	51.3	41.4	172.8	—	28	04	08.5	39.9	175.4	—
18	08	23.7	45.8	167.6	I	28	15	42ca	41.8	172.3	III
23	09	20.4	45.8	167.6	V	29	03	27.6	42.5	172.8	IV
24	19	13.8	41.6	173.8	IV	29	22	05.5	39.8	175.3	II
26	14	20.8	38.9	178.6	IV	31	02	03.9	40.5	175.0	I
29	05	10.0	39.8	174.4	III	31	10	22.9	42.5	173.0	IV
29	07	22ca	46.6	168.3	II	Nov.					
29	18	59.9	42.5	173.0	III	1	11	32.2	39.3	175.4	II
Aug.						3	05	44.5	37.7	175.8	—
12	01	03.2	42.2	172.6	—	3	16	21.9	40.2	174.9	—
14	07	02.1	38.3	176.5	—	4	02	21.3	43.3	171.4	II
14	20	01.6	35.2	179.3	—	10	05	00.1	37.3	176.3	—
14	23	39.6	35.3	179.2	—	10	09	51.9	38.5	176.1	—
15	01	14.3	35.4	179.3	—	11	04	37.3	42.5	172.9	III
16	13	50.8	39.2	178.0	IV	11	15	37.9	40.6	172.6	V

Origin Time. (G.M.T.)*		Epicentre :		Max. Felt Inten- sity. (M-M)	Origin Time. (G.M.T.)*		Epicentre :		Max. Felt Inten- sity. (M-M)
1948	h. m.	Lat. S (deg.)	Long. E (deg.)		1948	h. m.	Lat. S (deg.)	Long. E (deg.)	
Nov.					Dec.				
14	05 56.0	42.5	173.5	—	13	10 59.5	40.7	172.0	II
17	21 54.6	40.2	175.1	III	17	10 36.2	41.2	172.5	III?
25	19 42.9	40.2	175.1	III	17	13 51.3	39.5	180.0	—
28	12 03.3	38.2	176.6	—	19	02 54.3	42.6	172.7	—
30	14 07.7	42.7	172.8	—	20	21 05.4	40.9	172.9	—
Dec.					21	03 01.6	38.6	177.1	III
7	08 19.6	39.5	179.5	II	27	15 23.8	41.1	175.2	—
7	12 36.8	41.5	172.7	—	28	00 49.3	41.0	174.8	IV
8	03 07.2	34	179	—	29	11 25.8	42.2	172.8	—
13	09 30.4	40.7	172.7	III					

* G.M.T. (Greenwich Mean Time) is 12h. 00m. slow on New Zealand Standard Time.

REVIEW: THE HANDBOOK OF THE HEAVENS

NEW HANDBOOK OF THE HEAVENS. By Hubert J. Bernhard, Dorothy A. Bennet, and Hugh S. Rice. Revised Edition. Pp. 360. Whittlesey House, McGraw-Hill Book Company, Inc. 1948. \$3.

This book raises the question as to the dividing lines separating handbooks, textbooks, and popular expositions. Up to a point this work is all three, and hypercriticism might consider it scrappy in consequence. Surprisingly enough the reader will not find this mixture of treatment in any way confusing, but from a beginner's point of view a means of developing interest.

Anyone desiring to make a beginning in general elementary astronomy could not do better than have this book as a companion for a year. The success of the work is due to several factors. Simple statements without any attempt at romancing, but still retaining an abounding enthusiasm on the part of the authors is perhaps the main factor. Moreover, the reader is not merely told of certain matters, but where simple observations can be made to see things for himself, he is invited to have a look. Imperceptibly the reader becomes aware that astronomy is an observational science.

The authors are to be congratulated on the choice of illustrations, some of which are not commonly found in books of this type. Moreover, the plates and diagrams are selected to illustrate the arguments of the text, a matter which some books on astronomy seem to ignore.

A useful feature is the tabulation of telescopic objects, including Messier's catalogue. These have been chosen with good sense and care, such that any beginner with a moderate instrument can find good examples of the various object types. It is suggested that these tables might be collected together as a complete appendix in a future edition for increased reference value.

Occasionally one feels that there are small points upon which the perspective could have been improved, but this is more a matter of individual tastes. However, as one who lives under the Southern Cross, this is the first time on which the reviewer has seen or heard of the Coal Sack being called the Black Magellanic Cloud, which has much to commend it.

The production of the book as a whole is very good, and there appears to be an absence of any large errors.

I. L. T.,

23 June 1949.

NOTES ON THE PETROGRAPHY OF SOME NEW ZEALAND
COALS

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(Received for publication, 13 September 1948)

Summary

The general petrography of some New Zealand coals is discussed and Thiessen's petrographic nomenclature is advocated for application to New Zealand coals.

PETROGRAPHIC NOMENCLATURE

THE nomenclature used in petrographic studies of coal has been the subject of keenest controversy. Two methods of classifying the macroscopic and microscopic constituents of banded coal have arisen. The majority of American students of coal petrography have adopted the method pioneered by Thiessen based on the nature of the vegetable matter from which the constituents were derived; in Europe, however, Stopes' purely physical classification, without particular regard to source, has been more generally accepted (Moore, 1940, p. 20).

Stopes' terminology (Stopes, 1935) and definitions of the distinctive physical and chemical properties of the constituents (Stopes, 1919) are confined to Palaeozoic bituminous coals of fairly high rank. Many New Zealand coals are lower than bituminous in rank and as the physical and chemical properties of coal vary considerably with rank, Stopes' nomenclature cannot be applied to these. The examination of New Zealand coals of bituminous rank shows that while "vitrain", "durain", and "fusain", can be recognized fairly readily, the presence of "clarain" cannot as yet be determined with confidence. Difficulty in interpreting the description of "clarain" may possibly account for this. It should be noted here that originally "vitrain" was supposed to be structureless under the microscope. "Vitrain" was believed to be a solidified structureless jelly or colloid, produced by the complete disintegration and decomposition of plant material. Refinement of technique in the preparation of coal sections has shown that the "vitrain" band which does not show at least some traces of original cell structure is a decided rarity. It has been possible to demonstrate that not only do the "vitrain" bands of British bituminous coals retain their original cell structure in varying degrees of perfection, but also that these structures are practically identical with those of the "anthraxylon" bands in American coals of Carboniferous age (Raistrick and Marshall, 1939, p. 181).

Thiessen recognized the essential general petrographic similarity of coals of all ranks and ages. His nomenclature would thus seem to be readily applicable to New Zealand coal; examination shows that this is indeed the case.

Thiessen (1935) considered coal to be composed of two visibly different classes of constituents, anthraxylon and attritus.

Anthraxylon:

"Anthraxylon comprises the constituents of coal that are derived from the woody tissues of plants, such as stems, limbs, branches, twigs and roots, including both wood and bark changed and broken up into

THE PETROGRAPHY OF SOME NEW ZEALAND COALS

In this investigation surfaces from clean breaks and polished surfaces both perpendicular and parallel to the bedding planes were examined macroscopically. Thin sections for microscopic study were prepared using a slightly modified form of the paraffin-impregnation technique developed by Thiessen, Sprunk and O'Donnell (Thiessen, 1938).

MACROSCOPIC STUDY OF THE OHAI COALS.

Examination of coals from the Star, Mossbank, Black Diamond, Birchwood, Wairaki and Linton mines in the Ohai coalfield showed that anthraxylon and attritus can be distinguished macroscopically, the shiny, smooth-surfaced, black bands and lenticles of anthraxylon contrasting sharply with the dull, matt-surfaced, greyish-black attritus. Coarsely banded, finely banded, and micro-banded coal types (Thiessen, 1935) were observed.

In many of the coarsely banded specimens the "grain" (differential cellular structure) of the coalified wood could be recognized quite easily with the naked eye. Counts of the annual rings in two specimens of anthraxylon from a small outcrop near Malakoff Hill showed over eighty growth rings in each. A tendency to split along the grain was noted in a number of the larger pieces of grained anthraxylon, whereas the fracture of anthraxylon without noticeable grain, at an angle to the vertical cleavage and bedding planes, was usually sub-conchoidal to conchoidal.

In the vertical cleavage surfaces of the coarsely banded coal the anthraxylon bands were generally between 2 mm. and 1 cm. in thickness, although several thicker units—up to 8 cm.—were seen. In transverse sections the width of grained anthraxylon lenticles varied from 1 cm. to 15 cm. while longitudinal sections occasionally extended for half a metre or more. Measurement of the thickness and width of carefully selected transverse sections of grained anthraxylon in New Zealand coal seams may prove an aid to knowledge of the amount of compression which the seam has undergone. Variation in the amount of compression which lower and higher seams in a field have undergone may possibly be measured in this way.

Macroscopic study of the attritus showed that fusain was present in small quantities in all coals from the Ohai mines; in some cases large amounts were found, but these were very local in distribution.

Resin was likewise found in the attritus of all the Ohai coals, being particularly abundant in the upper "resin seams" (Lillie, 1945). The presence of resin in the Ohai coals, and in many other New Zealand coals, may be considered as evidence that conifers were present in the vegetation from which these coals have been formed. Conifers contain considerable quantities of resin stored in resin cells, ducts, and reservoirs in the wood, bark and leaves. "Wound" resin is also common in many conifers—the New Zealand Kauri, *Agathis australis*, is a good example. The resin in some living conifers may amount to as much as 10 per cent. of their dry weight (Thiessen, 1935).

The resin evidence for coniferous plants being represented in the coal-forming vegetation at Ohai is confirmed by pollen exine studies.

Pyrite crystals, up to 2 mm. in diameter, and small aggregations of other mineral materials can be seen with the naked eye in the attritus of some Ohai coals.

MICROSCOPIC STUDY OF THE OHAI COALS.

The grained anthraxylon when viewed in thin section invariably showed well preserved cellular structure. In several transverse and longitudinal sections the xylem and xylem rays were particularly distinct and in some the pitting of the cell walls could be distinguished. Microscopic examination confirmed the macroscopic identification of annual rings in the Malakoff Hill and other specimens. Inclusions of spherical ovoid, and ellipsoidal resin globules were quite common in the anthraxylon tissues, thus providing further evidence that conifers were present in the coal-forming vegetation at Ohai. The gymnospermous origin of several pieces of grained anthraxylon was determined by careful anatomical study of the xylem and xylem rays, and the nature and distribution of pitting. Detailed cellular structure of the pith, xylem, phloem, and cortex of a complete stem was observed in one set of sections. The anthraxylon was always dominantly yellow, orange or red in colour, but it is important to note that the intensity of colour and even the colour itself may vary with the thickness of the section.

Characteristic charcoal-like fusain with thick black cell walls and empty lumina was observed in attritus sections. Translucent humic matter, brown cell wall degradation matter, granular opaque matter, resin, cuticles, and mineral matter were also present in the attritus. A noteworthy feature of the attritus was the abundance of clear yellow spore exines.

PETROGRAPHIC CLASSIFICATION OF THE OHAI COALS.

An accurate petrographic classification of the Ohai coals would require serial roof-to-floor sectioning of individual seams. This could not be attempted by the writer. It is obvious, however, that most of the Ohai coals belong to the banded group and their place in this group could be determined without difficulty if the serial section work mentioned above were undertaken.

OTHER NEW ZEALAND COALS.

Hand specimens and thin sections of New Zealand coals, made available by the New Zealand Coal Survey, were also examined. Anthraxylon and attritus were identified macroscopically in Waikato, Ohura, Greymouth, Reefton, Charleston, Kaitangata, Taratu and Mataura samples. The presence of fusain as a common constituent in the attritus of many specimens was noted. In some coals pyrite and calcite are prominent as mineral matter constituents.

Resin is a constituent of the attritus in most New Zealand coals. Coals particularly rich in resin can be classified petrographically as resinous coals. The importance of resin as evidence of a coniferous element in the coal-forming floras of New Zealand has already been noted.

Microscopic examination of thin sections of coal from a number of the Greymouth mines confirms the suitability of the application of Thiessen's petrographic nomenclature to New Zealand coal, and the descriptions and figures given by Penseler (1932, 1933, 1934) in his account of the Waikato and James coals support this conclusion.

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REVIEW OF "TABLES OF SCATTERING FUNCTIONS FOR
SPHERICAL PARTICLES"

APPLIED MATHEMATICS, SERIES 4, 119p. 454, U.S. National Bureau of Standards.

These tables are designed to facilitate computations concerned with the angular distribution of intensity and total light scattered by a small spherical particle—such as a water-drop—in terms of size of particle and wavelength of the incident light.

Two interesting physical applications of the tables are given. The first relates to the estimation of particle size (assuming particles of uniform size) and the estimation of particle concentration. If the transmission of light of two different wavelengths through the particles is measured, then both these quantities can be quite easily determined.

The second application should prove very useful in the application of microwave radar techniques to meteorological phenomena. The radar echoes from water drops in the atmosphere are a particular case of the scattering problem where the scattering angle is 180° . Owing to the fact that the dispersion of liquid water occurs at microwave lengths (in the one to ten centimetre band, approximately), the refractive index becomes complex and depends on wavelength and hence scattering functions for complex arguments are required. These have been provided over the band of 3 millimeters to 10 centimeters.

I. D. DICK,

29 August 1949.

NOTES ON SOLAR ACTIVITY AND ASSOCIATED GEOPHYSICAL EFFECTS

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(Received for publication, 25 October 1949)

A radio-fadeout on the N.Z.-U.S.A. circuit which was associated in time with a small augmentation of the diurnal trend in all magnetic elements at Apia and Amberley occurred on 1949 May 10d. 20h. 05m. U.T. and was followed by a magnetic disturbance, aurorae and poor radio transmission conditions on May 12d.

From the sunspot records it seems safe to ascribe the origin of the disturbances to Sunspot, Carter No. 1112, in position, heliographic Latitude 17° South, Longitude 60° . The central meridian passage of this spot occurred on May 11-6d. U.T. At the time of original flare on May 10d. the spot would be situated 10° East of the central meridian. Unfortunately cloudy conditions at Wellington prevented observations of the Sun at this time.

The general appearance of the spot, which was attended by surrounding small spots, gave no indication of unusual activity when viewed with an ordinary telescope. Although the most prominent feature on the Sun, it was of only moderate dimensions, 775 millionths of the visible solar hemisphere.

In order that the inter-relation of solar, radio and magnetic data can be fully appreciated, the various phenomena have been set out in sequence below. In this table all times are U.T. and the letters in column 2 refer to:

				S = Solar Activity	I = Ionospheric Activity
				M = Magnetic Activity	R = Radio Receiving Conditions
				A = Auroral Activity.	
1949	d.	h.	m.		
May	10	20	02	S	Solar Flare Report in CRPL-F58
					Ionospheric Data-June 1949
			05	S	Sunspot 10° E of Central Meridian
				R	Fadeout N.Z.-U.S.A. Circuit
				M	Augmentation of diurnal trend in all magnetic elements at Amberley and Apia
May	11	02	04	M	Sudden commencement preceding minor magnetic disturbance
					Sudden commencement at Abinger, Greenwich, at this time.
					K-Index 4 00h.-03h. 03-06h. 11d.
	11-6			S	Central Meridian passage of sunspot
	12	06	42	S	Sunspot 9° West of Central Meridian
				M	Sudden commencement preceding major magnetic storm
		07	39	M	H element Amberley magnetic records commenced to decrease rapidly. Short period oscillations superposed on sharp irregular movements. Range until 15h. 24m. 527 gamma
		08	30	I	F2 layer ionosphere commenced to rise at speed 80km./hr.
		09	00	I	E2 layer suddenly appeared up to 1.4mc./sec.
		09	30	I	F2 layer became very disturbed
				A	Aurora first seen from Nelson H.A. DS.
		10	00	R	Quartz Hill: Signals half normal strength
		11	00	R	Makara: Conditions very poor, odd type of rapid flutter fading.
					Generally poor strength of signals
	12	11	00	R	Quartz Hill: Everything above 11mc./sec. completely blacked out, i.e. signal strength zero
		12	00	I	All trace of coherent F2 region vanished.
					Considerable amount of Es present and very scattered
		12	30	A	Brilliant Aurora reported from Gisborne, Grey-mouth, Auckland and South Australia
		13	00		Makara: All signals faded out
		14	00	R	
		15	24	M	H trace magnetic record commenced to show a gradual increase. Short period oscillations of large amplitude superposed on main trend.

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1949	d.	h.	m.	I	F region of Ionosphere vanished but may have been blanketed by Es and then reformed
May	12	19	00	R	Makara : Signals beginning to return slowly but generally weak up to 21h.
	13	04	00	M	Quieter conditions returned
	06	30	I	F2 layer remained above and f ^o F2 figures were below median values until this time	Aurora reported from Wellington H.A.
	08	45	A		
	11	45			

GENERAL

The solar eruption began a few minutes before the commencement of the radio fade-out on May 10d. 20h. 05m. and about 34 hours afterwards the magnetic storms commenced. This time lag indicates that the velocity of the particle radiation was of the order of 1200 km./sec.

ACKNOWLEDGMENTS

The Writers are indebted to Mr. H. W. Newton of the Royal Observatory, Greenwich, for advice concerning the geomagnetic "crochet" on May 10d. 20h. 05m. and the supplying of information relative to the Abinger Magnetic Records. Thanks are due also to the N.Z. Broadcasting Service and the Post and Telegraph Department for data concerning radio transmission conditions during the period in question.

REVIEW

CHAMBERS'S MATHEMATICAL TABLES

CHAMBERS'S FOUR-FIGURE MATHEMATICAL TABLES

L. J. Comrie, M.A., Ph.D.; iv. + 64 pp.; 1947; W. & R. Chambers Ltd., Edinburgh and London; published price, limp cloth 5/- net, cloth boards 6/- net.

CHAMBERS'S SIX-FIGURE MATHEMATICAL TABLES

L. J. Comrie, M.A., Ph.D.; Vol. I, Logarithmic Values, xxii + 576 pp., 1948; Vol. II, Natural Values, xxxvi + 576 pp., 1949; W. & R. Chambers Ltd., Edinburgh and London; published price, 42/- net each.

These new volumes of mathematical tables may well serve as a model for all makers and publishers of tables in the future, and it is safe to predict that they will become the standard collections of tables of elementary functions. The four-figure tables are intended for the highest school classes, technical colleges, and universities, as well as for industrial practice; the six-figure tables are intended for physicists, engineers, and practical mathematicians in general, and are to supersede the existing *Chambers's Seven-Figure Mathematical Tables*, which are to be allowed to go out of print.

The most striking feature of the volumes is that they have been prepared with the needs of the user constantly in mind. The use of non-lining (heads and tails) figures, carefully spaced both vertically and laterally, of bold-face type for arguments, and of white spaces rather than rules between columns, give such clarity and legibility that the tables can be used for hours on end without danger of eye-strain or fatigue. In provision for interpolation they are probably superior to any other tables published; where first differences do not suffice, a finer interval of argument or a critical table of an auxiliary function is introduced, attention being called to the need of such devices by the printing of differences in italics. Great pains have been taken to ensure accuracy. Part of the work of proof-reading involved a comparison with all available tables of the same functions, the result being to bring to light a number of hitherto unrecorded errors in the comparison tables.

A few of the tables are new, but even though many of them may have been published elsewhere, there have not previously been such convenient and comprehensive collections. In addition to logarithms and antilogarithms, they include trigonometric functions for sexagesimal, decimal, and radian arguments, natural logarithms, exponential and hyperbolic functions, inverse circular and hyperbolic functions, as well as powers, roots, reciprocals, factors, and interpolation coefficients. Many formulæ giving series, derivatives, integrals, etc., are included, and the explanations, written from the viewpoint of the practical computer, contain much that cannot be found in theoretical textbooks.

L. P. L.

26th October 1949.

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THE PREPARATION OF PLANT TISSUE FOR ANALYSIS

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(Received for publication, 10 November 1948)

Summary

Representative samples of grasses and clovers have been dried and extracted by a number of methods, and the extracts have been analysed for chemical constituents which are known to be relatively labile.

No method of drying has been found that consistently gives results comparable with those obtained with fresh tissue.

The method of extraction as well as that of drying has a marked effect on the results of a chemical analysis of the extract.

INTRODUCTION

In order to determine the chemical composition of plant material it is necessary that the majority of constituents be obtained in solution in such a way that extraction is complete and that no decomposition occurs in the process. A further problem which is frequently encountered is the necessity for dealing with a large number of samples at one time, so that a method of preserving, without appreciable change, either the original material or a suitable extract from it is very desirable. The wide diversity in current methods of preparation of extracts and of preservation of tissues is in itself an indication that the problem is very far from solution.

A large proportion of the published analyses of plant material has been performed on material which has been dried by one of a variety of methods before extraction. The use of dried material is undoubtedly convenient, as sampling errors are practically eliminated in finely ground material, while large numbers of samples can be dealt with in a short time. It is obvious, however, that unless the particular constituents have survived the drying and extraction processes, i.e., unless the final extract is truly representative of the original tissue, false conclusions will be drawn about its composition. In this paper are presented results for different preparative and extractive procedures. In making a selection of constituents for analysis special attention has been paid to labile and metabolically active materials; the choice of tissue was governed largely by the interest of the Plant Chemistry Laboratory in the chemistry of grasses and clovers which have the advantage of easy sampling while fresh.

METHODS OF DRYING

Electric Oven Drying:

The oven was of the electrically heated, forced draught type and was operated at $80^{\circ} \pm 2^{\circ}\text{C}$. Its efficiency was such that a 100 to 500 g. sample could be dried in 30 to 45 minutes.

Gas Oven Drying:

The oven was maintained at a temperature of about 60°C . by a series of small gas jets below the trays. Air movement was by convection only. A 500g. sample took about 24 hours to dry.

Flash Drying:

Drying took place in an inverted cone 22 in. high, 12 in. in diameter at the top and 2 in. at the bottom. A strong current of hot air was produced by a gas blow pipe operated at the intake of a centrifugal fan which was connected to the lower end of the cone. The material to be dried was placed either in 100 g. samples directly into the cone or in 50 g. samples in a wire mesh basket which fitted the top of the cone. At the beginning of drying the temperature measured at the base of the cone was adjusted to 200°C . and maintained at that temperature for two minutes. It was then lowered to 160°C . for the final two minutes of the process. A later improvement in the efficiency of the apparatus for the last flash drying reported in this paper enabled 200 g. to be dried in the cone in one batch. The temperature was maintained at 200°C . for two minutes and at 160°C . for three minutes.

Freeze Drying:

In the earlier experiments an all glass apparatus was used consisting of a desiccator to the tubulature of which was attached a condenser cooled by solid CO_2 and alcohol. The tissue was placed in the desiccator, the apparatus was evacuated to remove gases from the tissue and the condenser then filled with the refrigerant mixture. 60 to 80 g. of tissue could be dried in seven to ten hours. Later samples were dried in a locally made freeze drier with a condensing chamber maintained between -40° and -45°C . by a small commercial refrigerating unit. A manifold $1\frac{1}{4}$ in. in diameter connected to the chamber ended in four openings to which quart size milk bottles containing the tissue could be attached. By using four bottles in an air bath maintained at 30°C ., 500 g. of fresh tissue could be dried at a time. Drying was practically complete in 24 hours but was usually continued for 48 hours. With each equipment a vacuum of about 0.05 mm. could be maintained and the temperature of the tissue during drying was below -20°C ., so that the tissue remained frozen until dehydration was practically complete.

All dried samples were ground to pass 1 mm. mesh sieve in a small hammer mill, and were stored in tightly stoppered jars. The residual moisture content was about 5 per cent for all drying methods.

METHODS OF EXTRACTION

For the estimation of soluble nitrogenous and carbohydrate constituents the following methods of extraction were used. For ascorbic acid, carotene and peroxidase, special methods of extraction as described under "Methods of Analysis" had to be employed.

Cold Water:

Following the method of Reifer and Melville (1), 20 g. fresh or 3 g. dry material were placed in a screw capped Waring Blendor container

with 50 g. of ice chips, 10 ml. ether, and 50 ml. water. After blending for $2\frac{1}{2}$ minutes a further 50 g. ice was added and blending was continued for a further $2\frac{1}{2}$ minutes. The contents of the blender were made up to 250 ml. with the addition of a drop of capryl alcohol, if necessary, to reduce frothing. After an aliquot of 25 ml. was taken for sugar estimations, 0.3 ml. acetic acid was added to the remainder which was remixed and centrifuged. The supernatant liquid was used for the estimation of the soluble nitrogen compounds.

Hot Water:

For fresh material: 20 g. leaves were placed into 200 ml. boiling water and the boiling was continued for three minutes. The contents of the beaker were then transferred while hot to a Waring Blender, blended for three minutes, cooled and made up to 250 ml. An aliquot was then taken for sugar estimations and the remainder cleared with acetic acid as for the cold water extract.

For dried material: 3 g. ground material were placed in a 250 ml. volumetric flask and about 200 ml. water at 80°C. added. The flask was then shaken for 10 minutes in a water bath maintained between 80° and 85°C. The extract was cooled, made up to 250 ml. and treated as before. This extraction is essentially that of Vickery *et al.* (2).

Cold Alcohol:

20 g. fresh or 3 g. dry material were blended for three minutes in the Waring Blender with 200 ml. alcohol. Eighty-seven per cent alcohol was used for fresh tissue and 80 per cent for dry, so that in each case the final alcohol concentration was 80 per cent. The contents of the blender were then made up to 250 ml. with 80 per cent alcohol and centrifuged. Two hundred millilitres of the clear extract, to which about 25 ml. of water was added, was then concentrated *in vacuo* until all the alcohol was removed. The contents of the flask were again brought to 200 ml. with water and the extract centrifuged.

Hot Alcohol:

20 g. fresh or 3 g. dry material were boiled for three minutes with 200 ml. alcohol (87 per cent for fresh, 80 per cent for dry tissue). This was followed by blending for three minutes in the case of fresh material but for the dried samples blending was omitted. The extracts were cooled, made up to 250 ml. with 80 per cent alcohol, and then treated as for cold alcohol extracts.

ALCOHOL PRESERVATION

Cold:

20 g. fresh material were placed in a stoppered jar with 200 ml. 87 per cent alcohol, and the lid was screwed down tightly. At the end of the preservation period, either seven or eight days, the contents were blended for three minutes, made up to 250 ml. with 80 per cent alcohol and then treated as the other alcohol extracts.

Hot:

20 g. fresh material were put into 200 ml. boiling 87 per cent alcohol in a jar, boiling was continued for three minutes, and the lid screwed down tightly. After either seven or eight days the sample was treated as for the cold alcohol preservation.

METHODS OF ANALYSIS

Ascorbic Acid:

10 g. fresh or 2 g. dry material were blended for three minutes with 250 ml. (accurately measured) 3 per cent metaphosphoric acid. The extracts were filtered through glass wool and 10 ml. (or other suitable aliquot) titrated with 2:6-dichlorophenolindophenol. The amount of water in the sample was added to the volume of extractant in calculating the amount of material corresponding to the aliquot used.

Peroxidase:

Following the procedure of Morris, Weast and Lineweaver (3), 2 g. fresh or 0.5 g. dry material were blended for three minutes with 200 ml. 2 per cent NaCl. The extract was filtered through glass wool and diluted to a suitable concentration. Into a colorimeter test tube were placed 1 ml. $\frac{M}{2}$ buffer (pH 5.6), 1 ml. 2 per cent guaiacol, water to bring the final volume to 10 ml., a suitable aliquot of the extract, and finally 1 ml. 0.15 per cent H_2O_2 . The tube was immediately placed in the colorimeter (Coleman Universal Spectrophotometer, Model 11), and the absorption measured at one minute intervals using light of 420 $m\mu$ wavelength. The average increase in optical density per minute between the one minute and four minute readings was taken for the calculation which was based arbitrarily on colorimeter units per mg. of material. Although the results are expressed in arbitrary units they are comparable amongst themselves for different materials and different treatments.

Carotene:

10 g. fresh or 2 g. dry material were blended for three minutes with 50 ml. 20 per cent KOH, 300 ml. 95 per cent alcohol were added and the blending continued a further three minutes. The mixture was then transferred to a conical flask, refluxed for 20 minutes, and cooled. After the addition of 50 ml. water the contents of the flask were made up to 500 ml. with 95 per cent alcohol. An aliquot of 50 ml. was extracted with petroleum ether several times, the ether extract being then washed with water, passed through a column of $CaHPO_4$ and made up to 100 ml. The optical density was measured at 450 $m\mu$ and compared with that of β -carotene.

Ammonia Nitrogen:

A suitable aliquot (20 to 50 ml.) of the extract prepared as described in the section "Methods of Extraction" was distilled *in vacuo* with phosphate-borate according to the method of Pucher *et al.* (4). The ammonia was collected in 20 ml. 0.01N. HCl and measured with hypobromite and thiosulphate (5).

Glutamine Amide Nitrogen:

5 ml. extract with 10 ml. phosphate buffer (pH 6.5) was heated in a boiling water bath for two hours according to the method of Vickery *et al.* (6). The increase in ammonia due to the hydrolysis was attributed to glutamine and calculated as nitrogen.

Asparagine Amide Nitrogen:

Following Pucher *et al.* (4) 5 ml. extract with 1 ml. 6N. H_2SO_4 was heated in a boiling water bath for two hours, and the ammonia nitrogen was measured. The difference between this and the ammonia + glutamine amide nitrogen was attributed to asparagine.

Amino Nitrogen:

The residue from the ammonia determination was acidified and made up to a definite volume (between 20 and 50 ml.). 5 ml. aliquots were used for measurement of amino nitrogen in the Van Slyke manometric apparatus by the nitrous acid method. From the amount of amino-N found in this way 80 per cent of the glutamine amide-N was subtracted, in order to allow for the abnormal behaviour of glutamine under the conditions used for the estimation.

Total Soluble Nitrogen (T.S.N.):

1 ml. (or 0.5 ml.) extract was digested for 30 minutes with H_2SO_4 with phosphomolybdic acid as catalyst. The ammonia was then distilled off in a Parnas-Wagner apparatus, collected in 0.01 N. H_2SO_4 and titrated with hypobromite and thiosulphate.

"Identifiable" Nitrogen:

Is the sum of the ammonia-N, amide-N and amino-N.

"Rest" Nitrogen:

Is the difference between T.S.N. and "Identifiable" nitrogen.

Total Nitrogen:

5 g. fresh or 0.5 g. dry tissue was digested with 20 ml. H_2SO_4 with copper as catalyst, and the ammonia distilled off, using the usual macro-kjeldahl method.

Reducing Sugars:

The 25 ml. aliquot taken before precipitation with acetic acid was diluted to 100 ml. Aliquots of 3 ml. were taken for analysis by the ferricyanide method (7) using cadmium hydroxide as clearing agent (8). Reducing sugars were calculated as glucose.

Disaccharides:

50 ml. of the diluted extract as used for reducing sugars was inverted by the method described by Reifer and Melville (1). After inversion the volume was made up to 100 ml. and a 3 ml. aliquot was taken for clearing and analysis. Cold aqueous extracts from fresh and freeze dried material were always heated at $100^\circ C$. for three minutes before inversion to prevent extraneous enzymatic action. From the figure thus obtained for reducing sugars after inversion (expressed as glucose) was subtracted that previously obtained for reducing sugars, and the difference was taken as disaccharides.

Water:

5 g. fresh or 1 g. dry material were dried in a vacuum oven at $65^\circ C$. For fresh material the drying time was five hours and for dried material two hours. The loss in weight was taken as water.

Results were in most cases calculated to two significant figures and were always expressed as the amount of the particular constituent present in the dry matter.

RESULTS

Effect of Different Methods of Drying on Various Constituents:

In the first experiment perennial ryegrass, red clover, and white clover were dried under various conditions, the extracts in each case being compared with those prepared from fresh material by the cold water technique. Six constituents of widely different nature, viz,

ammonia, glutamine, reducing sugars, ascorbic acid, carotene, and peroxidase, were chosen for analysis. Estimations of carotene were later discontinued and were replaced by estimations of total sugars.

As soon as the sample was cut in the morning an aliquot was prepared in the Waring Blendor for immediate analysis. Samples for electric oven drying were of 100 g., while those for freeze drying in the smaller apparatus were of 60 to 80 g. Flash drying was carried out on 100 g. samples, in one operation when dried in the cone and in two operations when dried in the basket. Dried samples were analysed within a few days of preparation, the extractions for ammonia, glutamine, and sugars being by the cold water method. The results are given in Table I, all values being calculated on a dry matter basis.

TABLE I.

Tissue.	Treat- ment.	NH ₃ -N mg. per cent.	Gluta- mine Amide-N mg. per cent.	Ascor- bic Acid per cent.	Peroxi- dase units per mg.	Caro- tene mg. per cent.	Reduc- ing sugars per cent.	Disac- charides per cent.
Perennial Ryegrass 11/10/46	Fresh	4.1	26	.82	7.0	54	4.4	n.d.*
	El. Oven	14	21	.20	1.9	41	3.9	"
	Freeze	7.4	28	.46	2.8	40	4.6	"
Perennial Ryegrass 14/10/46	Fresh	5.6	22	.71	5.8	54	3.1	"
	El. Oven	6.2	16	.21	2.0	41	3.7	"
	Freeze	10	18	.58	5.9	45	4.6	"
Red Clover 22/10/46	Fresh	7.7	19	.64	29	35	4.6	"
	El. Oven	26	22	.10	3.6	43	5.1	"
	Freeze	12	27	.34	23	45	5.7	"
White Clover 24/10/46	Fresh	3.4	12	.92	59	53	5.1	"
	El. Oven	11	12	.28	33	41	4.5	"
	Freeze	4.0	15	.73	63	47	4.4	"
White Clover 21/11/46	Fresh	3.2	4.7	.88	58	46	7.0	"
	El. Oven	8.0	8.0	.42	35	36	6.4	"
	Flash	5.2	13	.64	2.5	34	4.8	"
	"	6.3	12	.59	3.7	37	5.2	"
	"	4.4	23	.67	2.4	38	4.6	"
	"	3.8	9.2	.63	2.2	37	4.0	"
Perennial Ryegrass 28/11/46	Fresh	2.3	5.3	.71	4.8	n.d.*	2.6	1.0
	El. Oven	4.8	7.2	.25	.82	"	2.6	1.2
	Freeze	3.5	8.5	.54	2.9	"	2.7	1.0
	Flash	4.4	26	.54	.03	"	2.1	1.3
	"	4.6	27	.51	0	"	2.1	1.1
Red Clover 29/11/46	Fresh	4.1	12	.60	21	"	3.2	0.9
	El. Oven	16	2.0	.08	3.9	"	3.5	1.0
	Freeze	4.2	8.8	.25	21	"	5.1	0
	Flash	5.6	4.1	.09	.20	"	3.1	1.0
	"	4.8	9.2	.08	.22	"	3.0	0.8
	"	5.9	7.1	.07	.22	"	2.9	0.7
	"	5.9	3.6	.08	.21	"	2.8	0.8
Brown Top 6/12/46	Fresh	16	33	.74	12	"	1.7	3.1
	El. Oven	15	20	.28	2.1	"	1.4	3.1
	Flash	8.1	18	.49	8.0	"	1.1	3.3

* n.d. = no determination.

Marked differences are apparent between fresh material and that dried in various ways. Ammonia shows an increase on drying in all cases except for brown top, a result in conformity with other results from the Plant Chemistry Laboratory (1). Drying in the electric oven gives the highest values while flash and freeze drying cause only slight increases over the fresh tissue. Glutamine values are more erratic. This is particularly true for flash dried tissue, the values for which on different aliquots of the same tissue show marked variations. The writers are unable to explain the occasional discrepancies shown by the legumes but the difference between fresh and oven dried samples on the red clover of 29th November 1946 is in line with other results they have obtained. It would appear that under certain environmental conditions both red and white clover contain substances which interfere with the estimation.

Ascorbic acid is lower in the dried materials, the extent of the decrease varying markedly with the method of drying. In general, freeze drying causes the least destruction, oven drying the most, with flash drying in an intermediate position. The results are in agreement with those obtained in vegetable dehydration.

Peroxidase activity is not seriously affected by the freeze-drying process but is markedly decreased by heat. However, even in flash dried samples complete inactivation is achieved in only one case, while in oven dried tissues as much as 50 per cent of the activity is retained. It is of interest that in the case of at least this one enzyme complete inactivation during dehydration by heat is not attained.

Values for carotene and the sugars vary much less than those for the constituents already discussed. The former in general shows some slight decrease on drying but differences between different methods of drying are scarcely significant. No consistent variation is seen in the sugar values which are fairly satisfactory for all methods of preparation, except that there is a tendency for reducing sugars to be decreased by flash drying. Freeze dried red clover (22nd November 1946) provides an interesting exception to the general rule in that the disaccharide component has apparently been quantitatively hydrolysed to monosaccharide. Kurssanov (9) has shown that invertase action is possible at temperatures below 0°C., but the writers can give no explanation as to the reason for complete hydrolysis in one case only.

In the second experiment two species only were used, the analyses were confined to ammonia, glutamine, and sugars, and all methods of drying were employed. Results are shown in Table II and are in general agreement with those of the previous experiment.

For the remainder of the investigation, analyses were confined to the soluble nitrogenous compounds and groups, and to the soluble carbohydrate, while the effect of extraction procedures was superimposed on the effect of different methods of drying. A 2 kg. sample of perennial ryegrass was cut from a plot which had been heavily fertilized a week previously with a complete fertilizer mixture containing ammonium sulphate. The sample, which was composed of leaves from two to three inches in length, was a very even one and sampling errors were reduced to a minimum. The tissue was divided into five lots of 400 g. each, four of these being dried by different methods. Electric oven drying was complete in 50 minutes at 80°C., while gas oven drying took 24 hours at 50 to 60°C. Flash drying was performed in two batches of 200 g. each,

TABLE II.

Tissue.	Treat- ment.	NH ₃ -N mg. per cent.				Glutamine-Amide-N mg. per cent.				Reducing Sugars per cent.				Disaccharides per cent.					
		18/3	19/3	21/3	26/3	28/3	18/3	19/3	21/3	26/3	28/3	18/3	19/3	21/3	26/3	18/3	19/3	21/3	26/3
White Clover	Fresh	3.5	5.6	2.9	1.6	4.2	16	16	17	9	18	3.5	4.2	3.4	2.5	1.4	.30	1.9	.84
	El. oven	12	11	14	7.8	11	16	12	13	12	15	2.5	3.7	3.4	1.9	2.6	1.8	1.4	1.4
	Freeze		7.0	9.4	6.4	6.2	16	16	20	15	17	3.8	2.7	4.3	.62	.62	3.3	3.1	1.1
	Flash	7.7	7.5	8.3	7.5	11	16	16	11	9	17	3.4	1.6	1.7	1.7	.89	.75	2.3	1.2
	Gas oven	15	17	21	18	20	15	21	16	19	22	2.7	3.2	2.7	3.3	2.6	.41	2.0	1.5
		17/3	20/3	21/3	26/3	28/3	17/3	20/3	21/3	26/3	28/3	17/3	20/3	21/3	26/3	17/3	20/3	21/3	26/3
Perennial Ryegrass	Fresh	3.2	2.5	3.9	2.4	3.2	7.6	8.7	12	16	20	1.5	2.1	2.5	2.1	3.0	1.6	3.3	.73
	El. oven	7.2	7.0	9.2	8.8	11	5.8	6.9	8.8	9.1	13	2.1	2.2	2.2	2.2	3.3	3.1	4.1	1.9
	Freeze		2.6	5.6	3.8	4.9	5.8	5.8	16	15	15	1.6	2.2	2.3	2.3	3.3	3.6	1.8	1.8
	Flash	3.7	2.9	3.7	3.3	5.3	6.2	4.6	6.1	8.1	12	1.6	1.7	1.3	1.4	5.3	2.2	4.6	2.5
	Gas oven	6.5	9.0	8.0	6.8	8.1	8.5	5.4	12	8.2	13	2.8	3.3	3.1	2.6	4.1	0	2.8	1.6

the temperature being held at 200°C. for two minutes followed by 160°C. for three minutes. Freeze drying was done in the larger model with mechanical refrigeration. The dried samples were ground, stored in tightly stoppered bottles, and analysed within a few days.

The fifth 400 g. sample was cut into $\frac{1}{2}$ in. lengths, remixed and 20 g. sub-samples taken for extraction with hot and cold water and alcohol respectively. Two additional subsamples of 20 g. each were stored in hot and in cold alcohol respectively. Results are shown in Table III, total nitrogen estimations being included as a check on sampling errors.

It is obvious from the table that differences due to extraction methods exist along with the differences already noted for preparative procedures. Striking differences are apparent in the ammonia found in the different extracts. On fresh material hot extraction yields much more ammonia than does cold, while the alcohol extracts are both lower in ammonia than the corresponding water extracts. For each of the dried samples, the same relationship holds although as would be expected the differences are much smaller. Again freeze drying gave ammonia values much closer to those of the fresh extract than did the other drying procedures. Both preserved samples show increases in ammonia comparable with those prepared by heat dehydration.

Glutamine values are again erratic, with apparent losses on flash and oven drying, but the differences between different extraction procedures on the same sample are relatively small. The asparagine values show large but fairly consistent variations. Cold water, hot water, and cold alcohol extractions on the fresh material indicate that the true asparagine figure is about 10 mg. per cent. After drying by any method the figure varies between 50 and 80 mg. per cent while preservation in hot or cold alcohol increases the value to 130 mg. per cent.

Amino nitrogen values for fresh, preserved, electric oven dried, and freeze dried samples are reasonably constant with no apparent bias in favour of any extraction method. Flash dried samples are low while the long drying period in the gas oven is reflected in high values.

The difference between alcohol and water extractions is shown most clearly in the total soluble nitrogen figures. In all cases, with the exception of the gas oven samples, alcohol extracts less total nitrogen than does water, both in the cold and in the hot. This is reflected in the "Rest-N" values. In fresh and freeze dried samples the sum of ammonia-N, and amide-N, and amino-N of alcoholic extracts is very close to the T.S.N. of those extracts, while the "Rest-N" figures on the alcoholic extracts of electric oven dried and flash dried samples are markedly less than those for the corresponding water extracts. The values for gas oven samples lead to the conclusion that considerable proteolysis has taken place during the long drying period.

The decrease in reducing sugars on flash drying which is noticeable in Tables I and II is again obvious, while there is a corresponding increase in disaccharides. In general, methods of extraction appear to cause less variation than do methods of preparation.

The final experiment was designed to extend the results of Table III to the other pasture species, viz, Italian ryegrass, cocksfoot, red clover, and white clover. The perennial ryegrass sample came from the same plot as had been used for the previous experiment, but 17 days later. The same analyses were performed as before but in order to bring the number of individual analyses to practicable proportions, the preparative and

TABLE III.

	Total N per cent.	Extraction.*	NH ₃ -N mg. per cent.	Glutamine Amide-N mg. per cent.	Asparagine Amide-N mg. per cent.	NH ₂ -N mg. per cent.	T.S.N. mg. per cent.	"Identifiable" -N mg. per cent.	"Rest" -N mg. per cent.	Reducing sugars per cent.	Disaccharides per cent.
Fresh	5.3	CW	4.2	120	6	380	750	510	240	3.7	4.7
		HW	16	110	13	390	750	530	220	3.4	6.0
		CA	3.6	120	13	380	570	520	50	3.3	5.1
Preserved		HA	11	96	39	410	490	480	30	3.0	5.6
		CA	25	90	130	370	690	610	80	4.1	4.1
		HA	24	82	130	390	650	630	20	3.0	5.5
Eli. oven	5.0	CW	33	79	76	410	780	600	180	3.6	4.3
		HW	33	83	77	400	830	590	240	3.3	4.9
		CA	25	75	70	360	660	530	130	3.2	4.6
Freeze	5.1	HA	26	65	80	410	680	580	100	3.3	4.9
		CW	7.4	110	61	380	680	560	120	3.4	3.8
		HW	12	110	47	420	780	590	190	3.1	4.4
Flash	5.2	CA	5.8	100	75	360	530	540	— 10	3.1	4.3
		HA	9.4	100	59	350	530	520	10	3.1	4.3
		CW	25	53	78	260	670	420	250	2.4	6.1
Gas oven	5.3	HW	30	61	77	290	690	480	230	2.4	6.1
		CA	22	50	67	220	520	360	100	2.2	4.8
		HA	24	50	70	280	660	420	140	2.5	5.6
Gas oven	5.3	CW	36	37	81	490	790	640	150	3.4	1.5
		HW	39	50	74	520	920	680	240	3.4	1.5
		CA	26	41	60	440	770	570	200	2.9	1.5
Gas oven	5.3	HA	27	38	76	490	930	630	300	3.2	1.4

* CW = Cold Water
 HW = Hot Water
 CA = Cold Alcohol
 HA = Hot Alcohol

	Total N per cent.	Extraction.	NH ₃ -N mg. per cent.	Glutamine Amide-N mg. per cent.	Asparagine Amide-N mg. per cent.	NH ₂ -N mg. per cent.	T.S.N. mg. per cent.	"Identifiable" -N mg. per cent.	"Rest" -N mg. per cent.	Reducing sugars per cent.	Disaccharides per cent.
Perennial Ryegrass	Fresh	Water	4.7	14	9	150	270	180	90	4.3	6.8
	Preserved	Alcohol	8.3	18	4	150	220	180	40	3.8	7.5
	Fl. oven	Alcohol	8.7	10	20	175	460	210	250	3.6	6.7
	"	Water	12	8	19	175	320	220	100	4.2	8.9
Italian Ryegrass	"	Alcohol	11	6	22	185	320	220	100	4.1	8.7
	Freeze	Water	7.3	12	21	150	320	190	130	4.0	7.6
	"	Alcohol	7.8	9	16	155	210	190	20	4.0	8.0
	Fresh	Water	3.8	9	12	125	200	150	50	4.3	7.2
Cocksfoot	Preserved	Alcohol	6.7	11	8	120	150	150	0	4.3	7.1
	Fl. oven	Alcohol	4.6	9	18	130	160	160	0	4.4	7.0
	"	Water	7.8	6	7	150	350	170	180	3.8	7.2
	Freeze	Alcohol	6.4	4	5	160	240	180	60	4.1	6.9
White Clover	"	Water	5.5	7	9	120	220	140	80	4.3	5.9
	"	Alcohol	4.9	5	13	145	210	170	40	4.6	5.4
	Fresh	Water	3.4	18	22	165	330	210	120	1.4	2.1
	Preserved	Alcohol	4.2	13	17	145	230	180	50	1.3	2.3
Red Clover	Fl. oven	Alcohol	4.3	8	15	170	220	200	20	1.2	2.4
	"	Water	13	9	12	195	450	230	220	1.5	1.9
	Freeze	Alcohol	9.6	4	14	175	365	200	165	1.4	2.0
	"	Water	5.4	17	15	155	300	200	110	1.3	1.9
White Clover	"	Alcohol	3.1	11	18	170	200	200	0	1.4	2.2
	Fresh	Water	3.5	14	62	175	435	240	195	4.2	2.8
	Preserved	Alcohol	5.4	11	67	200	470	270	200	3.2	2.0
	Fl. oven	Alcohol	5.9	8	34	185	250	230	20	3.1	2.8
Red Clover	"	Water	14	13	77	265	1000	370	630	3.9	2.7
	Freeze	Alcohol	14	7	67	200	700	290	410	4.0	2.5
	"	Water	6.2	14	58	210	510	290	220	4.3	2.0
	"	Alcohol	4.3	11	59	190	350	260	90	3.6	2.1
Red Clover	Fresh	Water	6.0	12	44	195	330	260	70	3.8	1.9
	Preserved	Alcohol	9.0	8	47	230	290	290	0	3.3	2.2
	Fl. oven	Alcohol	3.0	8	30	240	270	280	10	3.7	1.8
	"	Water	21	0	48	260	630	330	300	3.1	1.6
Red Clover	Freeze	Alcohol	14	3	41	230	380	290	90	2.8	1.2
	"	Water	4.5	44	44	220	330	270	60	3.5	1.6
	"	Alcohol	1.9	5	35	230	250	270	20	3.2	1.8

extraction procedures were much curtailed. Flash and gas oven drying were omitted for reasons which are apparent from previous tables. It was also considered justifiable to omit one alcohol and one water extraction, retaining hot alcohol extractions in all cases and hot water extraction for oven dried material. For fresh and freeze dried materials cold water extractions were used largely on account of the ammonia-N determinations. Preservation was by hot alcohol only and the samples were analysed after eight days.

Results are shown in Table IV.

The ammonia and glutamine figures require no comment other than to draw attention to the continued and unexpected variation which is apparent in the latter. The inexplicable variation in asparagine noted in Table III is again in evidence with perennial ryegrass but is shown neither by the other grasses nor by the clovers. Total soluble nitrogen is highest in all cases in the aqueous extract from oven dried material, the next highest values being given by alcoholic extracts of the same material. The increase in oven dried white clover is particularly marked. "Rest" nitrogen values parallel those of soluble nitrogen, while sugar values show no unusual features.

DISCUSSION

It is significant that, with the multiplicity of preparative and extractive procedures reported in the literature, there are few comparisons of these procedures as applied to the analysis of various constituents. Collins and Shorland (10) investigated different methods of preservation of ryegrass, viz, boiling alcohol, boiling water, freezing at -9°C ., -22°C ., air drying at 35°C ., 70°C ., 105°C ., and 120°C ., and bottling. These workers were concerned with preservation rather than extraction, and used as criteria ascorbic acid, phosphatides, free fatty acids and sugars, materials which except for ascorbic acid are less labile than many of the nitrogenous constituents used in the present investigation. Their results and those reported in this paper are therefore not comparable. Most workers are interested in the variation of one or more metabolites under different environmental or cultural conditions, and recognized methods of preparation and analysis are adapted to the problem, without too close an enquiry into the values which might have been obtained by the same analytical procedure applied to extracts prepared in other ways. This approach is in general justified since, as each analysis is done on material prepared in the same way, systematic errors will be of the same order of magnitude throughout. Thus, providing certain safeguards are applied, differences between analytical results are a reflection of real differences in concentration of the constituent in question. Nevertheless, the results reported in this paper show what care must be exercised in interpreting the results of indirect analytical procedures for single constituents or groups of constituents.

The variation in the ammonia values under different preparative procedures has already been the subject of investigation in the Plant Chemistry Laboratory (1), and further work on the ammonia precursors in plant tissues is in progress. All tables show clearly the large variations which may be expected, not only by different drying procedures but by different extraction methods on the same material.

The amides glutamine and asparagine show larger variations than had been expected. The former is notably unstable, being hydrolysed under conditions which have little effect on asparagine, but the work of

Vickery, Chibnall and their collaborators have defined fairly clearly the conditions under which extracts can be prepared without serious loss of this constituent. For instance, the times and temperatures of drying in the electric oven, viz., about 30 minutes at 80°C. for most samples, certainly causes only minimal changes in glutamine. Similar conclusions can be drawn with regard to freeze drying where, despite the length of time required for complete dehydration, the temperature of the tissue is below -20°C. and whatever water is present exists as ice. Further, there is no reason to suppose that the methods of extraction are in any way inadequate, or that significant amounts of glutamine are left behind in the residues. It would be expected therefore that glutamine values would be relatively consistent in so far as fresh, electric oven and freeze dried samples are concerned. The results show that this is not the case and that large variations do occur.

Unquestionably part of this variation is due to the variation in free ammonia values, an effect which is particularly well demonstrated in Table III. Here the sum of ammonia and glutamine on fresh, electric oven and freeze dried samples varies for all methods of extraction within relatively close limits, viz., 90 to 130 mg. per cent. Omitting the alcoholic extractions on oven dried tissue these limits are narrowed to 110 to 130 mg. per cent. For reasons detailed elsewhere (1), it is believed that the difference in ammonia values between extracts of fresh and oven dried material is not due to glutamine breakdown, and hence for this particular sample the true glutamine figure is probably that shown under "electric oven," viz., about 75 mg. per cent.

This explanation, however, does not cover all cases. The clover samples are notably erratic throughout and the writers believe that independent methods of analysis must be used before any true estimate can be formed of the glutamine concentration in these tissues.

Attention has already been drawn in the discussion of Table III to the anomalous behaviour of asparagine amide-N when perennial ryegrass is dried or preserved in alcohol. Obviously these relatively gentle procedures have resulted in the production of "amide" groups from some constituent or constituents which were originally resistant to hydrolysis by $\text{N.H}_2\text{SO}_4$. No evidence as to the nature of these constituents can be given but it seems highly improbable that the true asparagine content should rise from one per cent of the total soluble nitrogen to 10 per cent as a result of oven drying or to nearly 20 per cent by preservation in alcohol.

This anomalous behaviour of asparagine amide-N is apparently confined to perennial ryegrass among the tissue examined. However, the values for Italian ryegrass are by no means satisfactory and the general conclusion is that this indirect determination on a complex tissue, such as a green leaf, leaves much to be desired. Definite evidence for the inadequacy of indirect methods of amide analysis comes from the work of Vickery and collaborators on tobacco stem tissue (11), and their comments are valid for tissues other than tobacco. Rhubarb tissue which was fully investigated by the same workers (12) furnishes still further evidence of the difficulties presented by ammonia and by the constituents yielding ammonia on mild hydrolysis. The present investigation supports their repeated warnings as to the validity of current procedures.

The lack of qualitative knowledge of green leaf extracts is shown in the columns headed amino-N, total soluble-N, reducing sugars, and

disaccharides. In all cases complex groups of compounds are collected together by virtue of their possession of one or another common property, but very little is known of the individual compounds or of the extent to which the various compounds in the group contribute to the group figure.

The peroxidase estimations shown in Table I are of importance in that they demonstrate that enzymes can survive heat dehydration processes. The assumption has been made by several investigators that oven drying at temperatures close to 100°C. causes rapid inactivation of the enzymes present in plant tissues. This is obviously incorrect for peroxidase, while other evidence collected in the Plant Chemistry Laboratory shows that enzyme complexes involved in the production and transference of ammonia are not entirely inactivated by oven drying. Moreover, there is probably a period during oven drying when the condition of the tissue is favourable for enhanced enzyme activity.

ADDENDUM

This paper had been practically completed when the paper by Davies, Evans and Evans (13) appeared. These workers also recognize the limitations of existing methods of drying and preservation and describe in detail the method of freeze drying as applied to pasture species. While the writers agree that freeze drying possesses many advantages over other methods of dehydration, they feel that the evidence presented in this paper does not justify the assumption that freeze dried tissue is identical with fresh, and they believe that frequent check analyses against fresh extracts are desirable.

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OBSERVATIONS OF ScS NEAR AN EARTHQUAKE
EPICENTRE

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Summary

This paper records observations of ScS at three stations for the earthquake of 1948 January 15d 05h 01m 44s U.T. (at epicentral distances of $0^{\circ}.92$, $2^{\circ}.25$ and $3^{\circ}.45$) a range that, so far as is known, is barren of observational material for this phase.

Usually ScS is not recognizable in seismograms with epicentral distances less than about 10° . Although, for some years a watch has been kept on the local seismograms analysed at the Dominion Observatory, Wellington, for the occurrence of ScS at short distances, the first time that its appearance has been definite was for the earthquake of 1948; except that, for the deepest focus yet encountered for the New Zealand region, 1942 June 27d at a depth of approximately 400 km., an ScS was recorded at $2^{\circ}.25$ at Auckland. From a search of the seismological literature at the Dominion Observatory, three references to recordings of ScS at short distances for very deep earthquakes were found. Wadati (1933) gave evidence for ScS at $6^{\circ}.5$ for the 300 km. deep earthquake of 1932 November 13d. Berlage (1937) refers to the excellent records of ScS at Amboina; and again the same author (1939) gives evidence of ScS at Amboina at $3^{\circ}.5$ for a 400 km. earthquake in the Banda Sea on 1938 April 4d. Lastly, Visser (1937) shows a seismogram of ScS at $5^{\circ}.1$ for Amboina for a 700 km. deep earthquake on 1934 June 29d.

Knowledge concerning S waves reflected from the core appears to date from the early 1930's. Jeffreys (1944-45a) states that "... the first published readings of them (PcP and ScS) seem to have been in a paper on a deep focus earthquake by F. J. Scrase (1933), in which the surface waves were small, and Gutenberg and Richter have recently found them readable in normal earthquakes on the records made by short period instruments. Their existence is decisive evidence that the core boundary is a discontinuity." Tillotson (1939) observed ScS extensively on seismograms from $8^{\circ}.9$ to $101^{\circ}.5$ and it is from these and similar studies that the phase is known. Jeffreys and Bullen (1940) however, in their travel-time tables, tabulate ScS from 0° to 100° .

This paper records observations of ScS at three stations for the earthquake of 1948 January 15d 05h 01m 44s U.T. at epicentral distances of $0^{\circ}.92$, $2^{\circ}.25$ and $3^{\circ}.45$, a range that, so far as is known, is barren of observational material for this phase.

This earthquake was felt quite widely over New Zealand as is evident from the isoseismal map shown in Fig. 1. The maximum intensity of VI, estimated on the Modified Mercalli Scale of 1931, was felt in the Wanganui District. A notable feature is the favourable transmission of the energy along the main structural axis of the eastern districts of the North Island and the consequent extension of the felt area often noted in isoseismal maps of New Zealand earthquakes. The routine epicentre, as published in the monthly P-Bulletin issued by the Dominion Observatory, Wellington, was determined as $40^{\circ}.35S$ $175^{\circ}.0E$, using travel-time curves based upon those of Wadati for Japan and modified slightly for

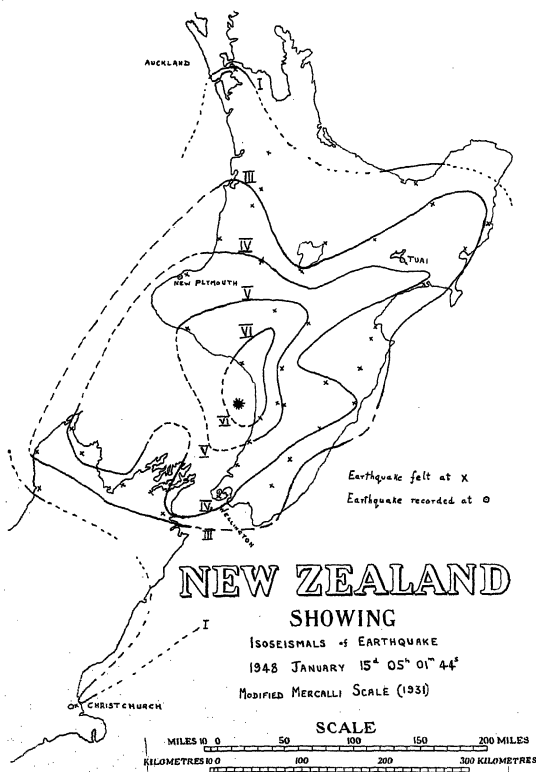


FIG. 1.

New Zealand conditions. The depth thus found to give the best solution was 80 km. The magnitude of the shock as calculated from the recorded amplitudes on "standard" Wood-Anderson seismographs (Gutenberg and Richter 1942) was $M = 5.5$.

An endeavour was made to collect all possible information relating to this earthquake and the writer is pleased to be able to acknowledge very active co-operation from overseas institutions. The results of this survey show that nine seismological institutions outside New Zealand recorded phases that were capable of interpretation, viz. Riverview and Brisbane in Australia, and seven stations in the Pasadena network of California.

New Zealand observations are set out in Table I:—

TABLE I

Station.	Phase.	G.M.T.			Semi- Amplitude. (mm.)	Estimated Time Accuracy. (sec.)	Seis. Type.
		h.	m.	s.			
Wellington	iP	05	02	04.5	22.5	$\pm \frac{1}{2}$	W-A
	iS			18	67.5+		
	ScS		16	54.5	0.5		
New Plymouth	iP	05	02	10	28.5	$\pm \frac{1}{2}$	W-A
	iS			29	63 +		
Tuai	iP	05	02	18	17.5	$\pm \frac{1}{2}$	W-A
	iS			45	70.5		
	ScS		16	56	0.4		
Kaimata	eP?	05	02	37	4	± 1	W-A
	S		03	17	11 +		
Christchurch	iP	05	02	09	8	± 1	W-A
	S		03	21	22 +		
Auckland	eP	05	02	34	6.1	± 2	M-S
	S		03	14	37		
	ScS		16	57	0.5		

(recognizable as short periods among surface wave periods rather than as distinctive amplitudes)

W-A = Wood-Anderson seismograph of natural period approx. 0.8 sec.

M-S = Milne-Shaw seismograph.

It was thought desirable to re-determine the epicentre using the Jeffreys-Bullen tables. It will be noticed that the three nearest stations all record iP and iS, the intervals in each case being measurable to the nearest 0.5 sec. Also, there is little reason to believe that the absolute times at these stations are in error by more than one second. Thus quite an accurate epicentre was found using these three stations; the other three stations also provided arcs based on less accurate information which, nevertheless, reliably confirmed the solution. The depth that provided the best solution was $h/R = 0.005$. Assuming a crustal thickness for New Zealand of 33 km. and following Bullen (1947),

" $h/R = 0.10 = 634$ km. below the crustal layers."

Thus $h/R = 0.005 = 32$ km.

The depth of the focus from the surface of the earth is 65 km. Apart from the uncertainty in the value assumed for the crustal thickness in the region of Wanganui this depth is regarded as accurate to ± 15 km.

Unexpectedly, the epicentre as determined by using Jeffreys-Bullen curves is precisely that obtained by using the "modified" Wadati curves, although the solutions were made six months apart and quite independently of one another. This provides good confirmation of the accuracy of the "B" class epicentres as published monthly in the Local Earthquake section of the P-Bulletin of the Dominion Observatory, Wellington. The data thus obtained is as follows:

Station	Distance
Wellington	0° 92
New Plymouth	1° 47
Tuai	2° 25
Auckland	3° 45
Kaimata	3° 46
Christchurch	3° 6

$h/R = 0.005$, $M = 5.6$, $H = 05h\ 01m\ 44s\ U.T.$; $40^{\circ}35'S\ 175^{\circ}01'E$.

From this epicentre, geocentric distances were computed to the nine overseas Observatories that recorded phase detail, by a method explained by Comrie (1938). These are given in Table II below, as are all the measured phases on the overseas seismograms. Observed travel times were computed, using the origin time shown above.

TABLE II.

Geocen- tric Distance.	Station.	Phase.	G.M.T. h. m. s.	A.	Travel Time. m. s.	Remarks.
20 04	Riverview	iS?	05 10 01		8 17	Only definite phase discern- ible, period = 7 sec. Ground ampl = 17μ .
22 14	Brisbane	iP S	05 06 37 10 37		4 53 8 53	From Benioff From Milne- Shaw
96 22	Pasadena(N-S) (E-W)	e e e ePP e iP i e e e i ePP i e	Not the slightest 05 15 08.5 24 31.5 18 58.5 19 09 05 15 04.5 08 20.5 32 51.5 16 06.5 18 59 19 06.5 19	5 3 4 4 4 9 9 5 6 7 5 12 11 7	13 24.5 40 47.5 17 14.5 25 13 20.5 24 36.5 48 14 07.5 22.5 17 15 22.5 35	Excellent Phase
96 30	Mt. Wilson	eP i e iPP	05 15 05 15.5 28 19 00.5	6 4 3 8	13 21 31.5 44 17 16.5	
96 35	Palomar(N-S) (E-W) (U-D)	P PP eP i e iP i i e iPP	05 15 06 19 00 05 15 07 58.5 19 01 05 15 06 28 58 16 11.5 18 59	9 9 7 6 4 26 11 11 8 10	13 22 17 16 13 23 14 14.5 17 17 13 22 44 14 14 27.5 17 15	Wave Period 1.4 sec.

TABLE 11.—Continued

Geocen- tric Distance.	Station.	Phase.	G.M.T.		A.	Travel Time.		Remarks
			h.	m. s.		m.	s.	
96 44	Riverside	iP	05	15 06.5	10	13	22.5	Perfect Phase
		e		17	6		33	
		e		31	5		47	
		i		43	6		59	
		iPP	19	00	6	17	16	
		e		08	5		24	
		e		32.5	4		48.5	
		e		47.5	3	18	03.5	
97 53	Haiwee	e	05	15 23	2	13	39	
		ePP?	19	07	3	17	23	
		iPP?		13	4		29	
98 23	Tinemaha	e	05	15 23	2	13	29	Very small
		i		26	5		42	
		i		37	2		53	
		ePP	19	13.5	6	17	29.5	
		e		22	5		38	
		e		29	4		45	
		e		35.5	4		51.5	
		i		55	5	18	11	
99 32	Tucson	iP	05	15 20	11	13	36	Rises to good amplitude
		e		25.5	8		41.5	
		iPP	19	23.5	8	17	39.5	

A is the double amplitude in units of 0.1 mm. . . . it is arbitrary for Palomar.

A plot of the Jeffreys-Bullen curves for P and PP from 95° to 100° is shown in Fig. 2. The five stations which recorded P did so very precisely, the values lying closely on a curve parallel to both 0.00 and 0.01 and intermediate to them. This gives a striking confirmation of the depth range previously obtained, i.e. $h/R = 0.005 (\pm 0.0025)$ or $65 (\pm 15)$ km. It is noted that the P waves, having travelled entirely across the Pacific Basin, may have arrived a few seconds early. This would cause them to indicate a slightly greater depth than the actual value for the earthquake when plotted as in Fig. 2. Such an effect appears to be observed! (Gutenberg and Richter 1946; and Bullen 1948).

The PP Group, although not recorded with the precision of the P Group, is present. No waves of any other type were recorded in California.

The comparison of the Jeffreys-Bullen with the observed times for the three Australian phases is shown below.

TABLE 111.

Geocentric Distance.	Observed (O).		J-B tables (C).	
			0.00 m. s.	0.01 m. s.
20° 04'	8	17(iS?)	8 11.9	8 02.9
22° 14'	4	53(iP)	4 55.2	4 49.5
	8	53(S)	8 52.9	8 42.8

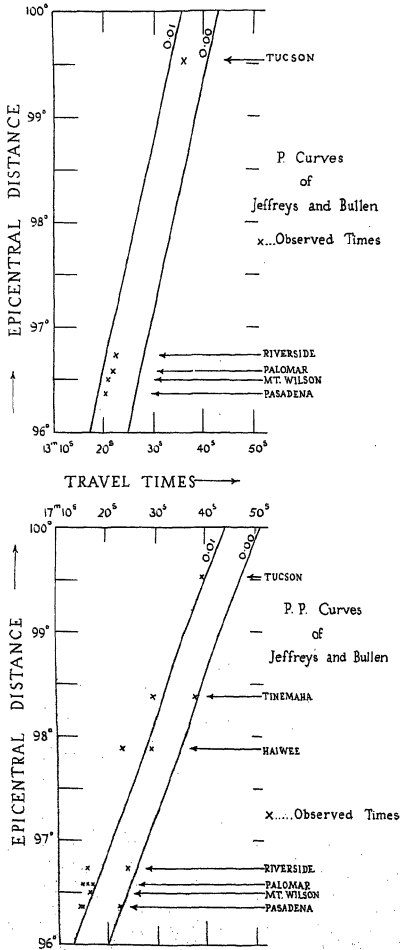


FIG. 2.

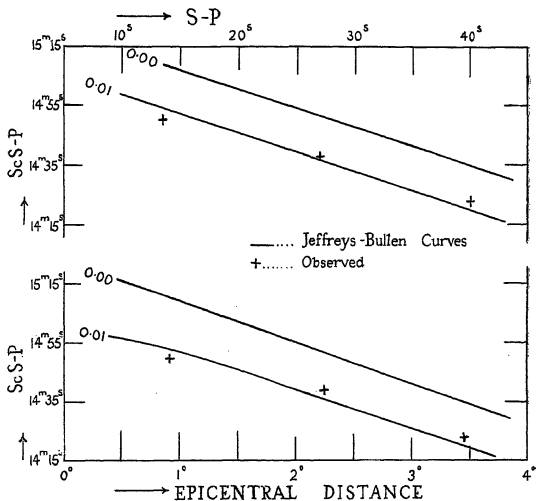


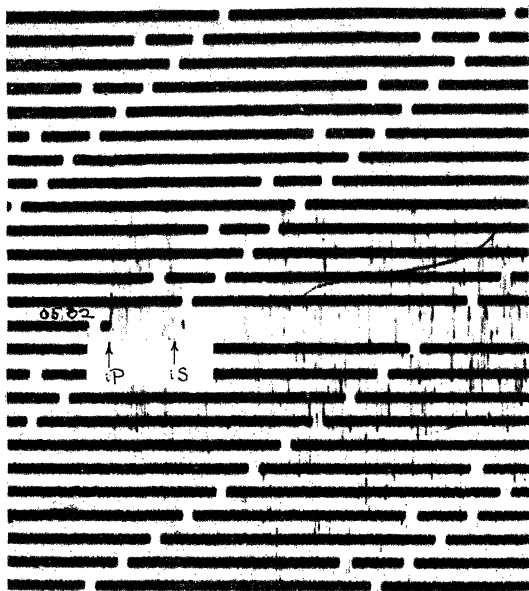
FIG. 3.

There is good agreement between the observed and calculated times for P at Brisbane. The S phase at Riverview is masked in heavy microseisms and is not particularly impulsive at Brisbane.

Finally the Jeffreys-Bullen curves have been plotted for ScS-P against S-P and for ScS-P against epicentral distance in Fig. 3. The observed values at Wellington, Tuai and Auckland are also plotted in Fig. 3. The Wellington P, S and ScS are shown in Fig. 4, and is typical of all three recordings. The Auckland record is from a Milne-Shaw seismograph and there the phase is distinctive because of its short period in comparison with the surrounding surface waves. The approximate periods of the ScS waves at Wellington, Tuai and Auckland are 2.0, 1.7 and 2.5 sec. respectively.

It will be noticed that the Wellington plot in each case is the most inconsistent with the previous findings. Although much more evidence would be required to prove it, this non-agreement may be related to some inconsistency in the ScS travel-time curve, especially as the slope of this curve is changing rapidly between 0° and 1°.

These close recordings of ScS provide an estimate of the depth of the core directly, as the S wave responsible has travelled down to and back from the core almost along the same path, and also raise the question as to the mechanism by which S waves can survive almost perpendicular reflection. Was the reflection in the present case due to the sharpness of the discontinuity known as the core boundary below the North Island of New Zealand? Or, alternatively, did the reflection



WELLINGTON SEISMOGRAM

1 MINUTE

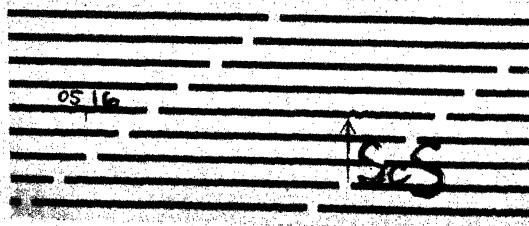


FIG. 4.

appear because of some particular property of the S wave-front, e.g., very sharp in onset, because of its generation by an extremely sudden impulse?

However, it may be concluded that the depth of the core of the earth underneath the North Island of New Zealand is close to the normal value accepted for the world as a whole (see Jeffreys 1939a, 1939b, and 1944-45b).

ACKNOWLEDGMENTS

The writer would like to thank Mr. R. C. Hayes, Director of the Dominion Observatory, Wellington, who, in addition to making this research possible, offered valuable suggestions during the progress of the work and kindly undertook to read the proofs. Help and encouragement were also received from Mr. G. A. Eiby and Mr. N. S. Mountier, of the Observatory staff.

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TOXICITY TO HOUSEFLIES OF A FLAT OIL PAINT CONTAINING D.D.T.

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(Received for publication, 27 August 1948)

Summary

Flat oil paints containing 5 per cent, 2.5 per cent and 1 per cent para-para-isomer D.D.T. were tested against houseflies. Paint with 5 per cent D.D.T. was found to be lethal to flies and, under conditions of the tests, retained its full toxicity for 385 days. The paint with 2.5 per cent D.D.T. gave comparable results but that with 1 per cent D.D.T. was not effective.

It was found that paint films containing D.D.T. were not toxic to flies to any extent until D.D.T. crystals formed on the surface. Once these appeared knockdown occurred in relatively short time.

Any form of light rubbing or brushing initiated crystal formation, insects walking across the surface being sufficient to start this process. Crystals did not appear until the surface was disturbed in some way.

INTRODUCTION

Investigations into the insecticidal action of paints in which D.D.T. was incorporated were first carried out by Campbell and West (1944). They discovered that both a dry distemper and an oil bound water paint containing D.D.T. were toxic to houseflies. A white lead oil paint and a synthetic varnish enamel containing D.D.T. showed no toxicity. Later West and Campbell (1946) recorded experiments showing the toxicity to houseflies, bedbugs and cockroaches of a flat oil paint containing D.D.T. Gilmour (1946) also tested paints containing D.D.T. against houseflies and showed that flat oil paints containing 3 to 5 per cent D.D.T. were very effective.

Tests are being conducted by this Division to determine the toxicity to houseflies of several types of paints containing D.D.T. and to establish the duration of their effectiveness. Results of the testing of a flat oil paint over a period of 385 days are recorded in this paper.

MATERIALS AND METHODS

A white flat oil paint was prepared in the following proportions: 1½ lb. pigment, 5 oz. linseed oil, 3 oz. resin, 6 oz. turpentine. D.D.T. was incorporated into samples of this paint by remilling to give D.D.T. para-para-isomer contents of 1.0 per cent, 2.5 per cent and 5.0 per cent (W/V). A sample containing no D.D.T. was used as a check paint. The four mixtures are referred to as 1.0 per cent, 2.5 per cent, 5 per cent and Check paints respectively.

Houseflies (*Musca domestica* L.) were used as test insects, those required for these tests being bred in the laboratory by a standardized technique (Harrison, 1950). Flies were 2 to 7 days old when used and in tests at each time interval flies used were reared from the one culture.

Test cages were of wood and wire gauze having internal dimensions 6 in. x 6 in. x 5½ in. (Fig. 1). Plywood, ½ in. thick made up five sides of each cage and the sixth consisted of wire gauze on a wooden frame. A hole, 1½ in. in diameter, cut in the side opposite the gauze served for introduction of flies into the cage.

Interior wooden faces of dismantled cages were primed with glue size and painted with the paint under test. One coat of paint was applied, the weight of this being determined in each case. Each test paint was applied to three cages. Table I shows the amount of D.D.T. present per unit area.

TABLE I. AVERAGE AMOUNT OF D.D.T. PER SQUARE FOOT
OF PAINT FILM ON TEST CAGES

D.D.T. Content of Paint. (Per cent. p.p.i.)	Average Amount of D.D.T. (mg. per sq. ft.) ¹
1.0	135
2.5	330
5.0	700

Before each test, all cages were assembled and placed in the testing room, which was maintained at the same conditions under which flies were reared; viz. temperature $28.0^{\circ} \pm 0.5^{\circ}\text{C}$. and relative humidity 53 per cent ± 2 per cent. Approximately 50 flies were transferred from a stock cage to each test cage by means of a glass chimney (Fig. 1). The cages were then arranged in the testing room so that all were equidistant from the source of light.



Photo by R. I. Hughes.

FIG 1.—Cages used for testing paints containing D.D.T.

Right: Assembled cage showing method of introducing flies.

Left: Assembled cage containing flies.

Front: Glass chimney with approximately 50 flies. X 1/6.

Exposure time was approximately 60 minutes or until complete knockdown of flies occurred, whichever was the sooner, except that exposure time of the first test was 120 minutes. After exposure, flies were transferred to recovery cages measuring 12 in. x 12 in. x 12 in. which were made of wire gauze on a wooden framework. The flies in these cages were supplied with a pad of cotton wool soaked in 10 per cent sugar solution as food. After use test cages were dismantled and hung in a store room where they were exposed to normal indoor conditions but protected from direct sunlight. After 24 hours flies in recovery cages were examined and percentage mortalities obtained. The same cages with the original coat of paint were tested throughout the period. The first test was conducted when cages had been painted two days and further tests were made when paint films were 14, 52, 92, 128, 190 and 385 days old.

RESULTS

Mean percentage knockdown for each set of three test cages over the 385 days testing time is given in Fig. 2. Results of cages treated with the check paint are not shown, as these cages gave no knockdown after 60 minutes in any test.

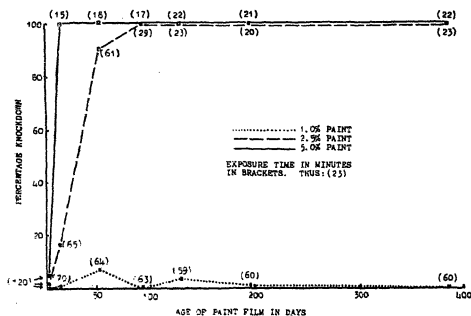


FIG. 2.—Mean percentage knockdown of houseflies from sets of three test cages treated with flat oil paints containing varying amounts of D.D.T.

Mean percentage mortality for each set of three test cages over the 385 days testing time is shown in Fig. 3. Results for the test at 52 days have been omitted because mortalities were influenced by contamination of recovery cages. With the 2.5 per cent paint complete mortality from the test at 385 days did not occur until after 24 hours.

NOTES ON THE CRYSTALLIZATION OF D.D.T. IN THE PAINTS

Crystallization of D.D.T. in paints has been recorded as a phenomenon by Gilmour (1946). He observed that with some paints (including flat oil paints) crystals of D.D.T. formed on the surface but he did not note that their formation depended on some form of surface disturbance. Somewhat similar phenomena have been recorded for solutions of D.D.T. Parkin and Green (1945 and 1947) noted that a solution of D.D.T. in kerosene when applied to an absorptive type of wall board formed a supersaturated gum-like residue, which, when

agitated slightly became covered with minute crystals of D.D.T. Busvine and Barnes (1947) recorded that an acetone solution of D.D.T. on glass dried to leave a super-cooled liquid which crystallized out fairly rapidly especially if stimulated mechanically. Cohen (1946) stated that the deposit from the production of D.D.T. smokes produced by burning impregnated filter papers consisted of minute droplets that remained liquid until mechanically disturbed by being brushed lightly or by movement of insects.

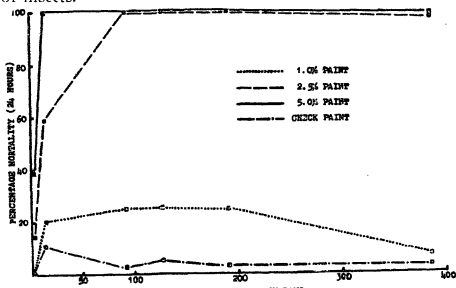


FIG. 3.—Mean percentage mortality of houseflies from sets of three test cages treated with flat oil paints containing varying amounts of D.D.T.

Examination of the cages in this series of tests was made at intervals with a binocular microscope.

Seven days after test cages were painted the surfaces of those treated with 5 per cent paint were carpeted with a mass of D.D.T. crystals. The 2.5 per cent, 1.0 per cent and Check paints did not show crystals. Crystals were fine and needle-like arising from the surface of the paint and were grouped in clusters which formed a dense mat on the surface. Typical crystals of D.D.T. on a paint film are shown in Fig. 4.

It was assumed that as the paint dried, crystals formed and were fully developed within a few days. Investigations were begun to find out how soon this occurred. Glass plates 2 in. x 2 in. were given one coat of 5 per cent paint and examined each day. Seven days after painting crystals had not formed. On the eighth day the plate edges were covered with crystals similar in appearance to those originally observed. These crystals appeared to have formed where the plates had been touched during examination. This was confirmed by rubbing a finger over a marked area and observing the surface later. After 24 hours the rubbed area was a mass of crystals, while the rest of the plate was free of crystals.

Various facts about the nature of this crystallization phenomenon with flat oil paint, brought to light by using 5 per cent paint on glass plates, are enumerated below.

1. That movement of flies on painted surfaces is sufficient agitation to cause crystal formation was shown by confining 20 flies on each of three painted glass plates by means of a circular pill box cage for one minute, five minutes and 16 minutes respectively. Later, examination of plates showed crystals formed but only in the circular areas exposed

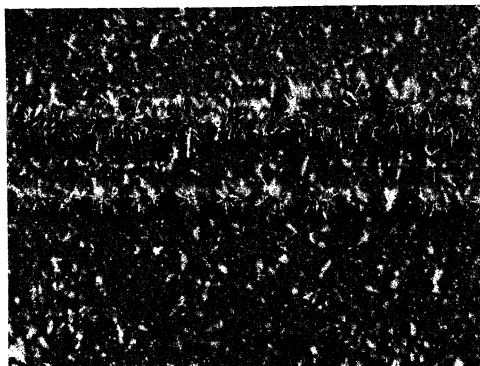


Photo by R. I. Hughes.

FIG. 4.—Film of flat oil paint containing 5 per cent D.D.T. on a glass plate showing D.D.T. crystal formation (two streaks) caused by running a soft brush over the surface. X 16.

to flies. The plate exposed for 16 minutes was thickly covered with crystals, that exposed for five minutes had fewer crystals while the plate exposed for one minute had only a few scattered streaks of crystals within the circle. This explained the occurrence of crystals on test cages on the seventh day since flies in the cages during the first test would have created sufficient rubbing effect by walking on the painted surfaces to cause crystals to form.

2. Disturbing a painted surface with a soft brush, or rubbing with a rag or with the hand was sufficient to cause crystal formation. This effect, however, was not produced by jarring or the settling of dust particles on the painted surface.

3. Crystal formation could not be initiated by mechanical disturbance until the paint film was five or more hours old.

4. The first crystals appeared two hours after a surface had been touched and were fully formed after 24 hours.

5. That a paint film did not crystallize spontaneously for at least six months after painting was shown by preparing glass plates with the 5 per cent paint and leaving them undisturbed and protected under gauze from insects. Observation at intervals showed that apart from a few isolated clumps crystals did not appear on the surface. Moreover at three and a half months an area of one slide was rubbed and 24 hours later a carpet of crystals was present. At five and six months other areas were disturbed with similar results.

6. Painted surfaces showed remarkable power of regenerating crystals. When once formed on a surface, crystals can be rubbed off easily but within a short period a fresh carpet appears. To determine the extent of this regeneration the painted surface of a glass plate was brushed to produce a covering of crystals. When fully formed these were rubbed off. The new crop of crystals which appeared was removed after 24 hours. This process was repeated several times and

resulted in six successive batches of crystals from the same surface. The last crystals to appear were not as large as previous ones but were still plainly visible under the microscope.

7. Crystallization of D.D.T. occurred on films made from paint which had been stored for six months. No differences were apparent between crystals formed from stored paint and those from freshly prepared paint.

8. With the comparatively slight disturbance of a surface by movement of flies, crystal clumps were less numerous and the individual crystals were longer than when the surface was disturbed by other means.

9. There were no differences in toxicity to houseflies between surfaces disturbed by flies and those disturbed by other means.

DISCUSSION

Figs. 2 and 3 show that when a test was made two days after painting, knockdown was very low with all paints and the maximum mortality—with the 5 per cent paint—was only 39.4 per cent. After 14 days the 5 per cent paint gave both 100 per cent knockdown and 100 per cent mortality, whereas the 2.5 per cent paint gave a very low knockdown and only 59.0 mortality. The 1.0 per cent paint gave a negligible knockdown and low mortality. In the third test, after 52 days, the 5 per cent paint again gave 100 per cent knockdown, that of the 2.5 per cent paint had increased to 90.5 per cent and at subsequent tests both paints gave complete knockdown and mortality. In the 385 days test, however, complete mortality from the 2.5 per cent paint did not occur until after the 24 hour recovery period and this may indicate a falling off of toxicity of this paint. The third, fourth and fifth tests with the 1.0 per cent paint gave results little better than the second. After 385 days mortality was almost nil.

At all tests after the first, the 5 per cent paint caused complete knockdown of flies in 15 to 22 minutes and at 385 days showed no increase in time required.

It was found that there was a correlation between the knockdown and mortality figures and the appearance of D.D.T. crystals on the paint. With the 5 per cent paint crystals were seen before the test at 14 days and were present over the whole subsequent testing period. The test at 14 days was the first to produce a complete knockdown in short time and a complete mortality. At seven days crystals were not present on cages painted with 2.5 per cent and 1.0 per cent paints and neither the knockdowns nor mortalities were complete with these paints at 14 days. Examination showed that crystals were first present on the 2.5 per cent paint films after the test at 52 days and results show that tests subsequent to 52 days gave fast complete knockdown and complete mortality. The 1.0 per cent paint films did not produce crystals at any stage of the test period.

That the 2.5 per cent and 5.0 per cent paints are highly toxic 385 days after application is shown. The ultimate duration of their toxicity would depend on the quantity of D.D.T. present, its rate of decomposition and the number of flies that walk across the surface. It is probable that a paint surface would be denuded of insecticide at a speed directly proportional to the number of flies walking over it. This has not been measured.

Although the paints have not been tested in the field a practical point in their use can be gained from this study. To make a D.D.T. flat oil paint toxic to houseflies it would be advisable to rub the painted surface in some way after it had dried. If painting was done in a fly-free period this brushing could be left until the first flies appeared. A rub over with a cloth or soft brush would be sufficient for the paint to become coated with a carpet of fine crystals. Painted surfaces could be cleaned periodically and yet regain their insecticidal properties.

ACKNOWLEDGMENT

Thanks are extended to Messrs. Proven Paint Products Ltd., Auckland, for preparation of the paints and to Mr. J. Kay for helpful suggestions.

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A NEW TECHNIQUE FOR THE INVESTIGATION OF ELECTROPOLISHING PROBLEMS

(Received for publication, 7 June 1949)

A technique has been developed, using anodes along which the current density is varied, for the investigation of electropolishing problems.

An investigation of the effect of varying the concentration of orthophosphoric acid, and of the addition of glycerol and Teepol on the electropolishing of copper was carried out.

It was found that, under certain conditions, satisfactory electropolishing is not, as previously thought, confined to the current density corresponding to the "anode plateau." It was also found that the addition of glycerol or Teepol could eliminate the pitting or marring of the surface as oxygen bubbles commenced to be evolved, although the addition of Teepol could adversely affect the finish.

A full account of this work is being prepared for publication.

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THE *Pittosporum* CHERMID, *Powellia vitreoradiata* MASK.

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(Received for publication, 21st October, 1947)

Summary

The *Pittosporum* Chermid, *Powellia vitreoradiata* Mask. occurs in the Auckland area, Palmerston North, Wellington and Motueka. It is said to be present throughout New Zealand.

The systematic position of the insect is discussed.

Host plants are *Pittosporum crassifolium* A. Cunn., *P. eugenoides* A. Cunn., *P. tenuifolium* Banks and Sol., *P. ellipticum* Kirk. Also recorded are *Discaria toumatou* Raoul and *Geniostoma ligustrifolium* A. Cunn.

Pre-adult forms are described, and keyed.

The length of life-cycle from egg to adult varied from 51-71 days with an average of 58 days. The condition of the host foliage was found to influence the length of life-cycle, development being fastest on young leaves.

The Chermid was observed to be present throughout the year, building up large populations during the main growing periods of the trees in the spring and autumn, the size of the population being relative to the amount of new growth produced by the trees, except in the summer when foliage produced in full sunshine hardened before the life-cycle of the insect was completed. This period was bridged by a limited number of nymphs which were able to mature on foliage growing low on the trees in the shade, and also by a number of adult females which were still capable of egg laying when the new foliage appeared in autumn.

One parasite and five predators are recorded. The most important of these was the lacewing predator, *Drepanacra binocular* Newm., and details of the biology of this insect are given. It was found to exercise a noticeable reduction in the Chermid population in the early spring, but was not effective as a control.

INTRODUCTION

THE Chermid, *Powellia vitreoradiata* Mask. causes a great deal of damage to young growth of *Pittosporum* trees, particularly the hedge plant *Pittosporum crassifolium* A. Cunn. It produces unsightly pitting on the foliage (Fig. 3) and stunting of growth, followed in severe cases by development of sooty-mould fungus on the honey-dew exuded by all stages of the pest.

The investigation reported in this paper was carried out primarily to ascertain the life and seasonal cycles of the insect in order to provide a basis for control measures.

SYSTEMATIC POSITION

The species was originally described from the fifth instar under the name *Powellia vitreoradiata* by Maskell (1879) as a member of the Coccidæ; later (1890) he placed it in its correct position as one of the Chermidæ (then called Psyllidæ) but described the adult as the new species *pellucida* in the genus *Trioza* Forster, thus rejecting his earlier specific name. This, however, was inadmissible, and Ferris and Klyver (1934), wishing to create a new genus in the Chermidæ for the species, restored both the specific name *vitreoradiata* and also the original generic name *Powellia* Mask.

HOST PLANTS

The host plants of the Chermids are:—*Pittosporum crassifolium* A. Cunn.; *P. eugenoides* A. Cunn.; *P. tenuifolium* Banks and Sol.; *P. ellipticum* Kirk. Maskell (1890) recorded also *Discaria toumatou* Raoul and *Geniostoma ligustrifolium* A. Cunn.

DISTRIBUTION

The insect is common throughout the Auckland area. The collection made by the Plant Diseases Division also includes specimens from Palmerston North, Wellington and Motueka. Maskell (1890) stated that the species was present throughout New Zealand.

DESCRIPTION OF LIFE STAGES

(a) Egg (Fig. 1F).

Shining; glabrous, irregularly lacrimiform, tapering towards the apex, which bears a short spine, with a short stalk situated to the side of the base. Colour when newly laid pale cream with basal quarter orange, darkening to pale orange with the basal third orange; some days before hatching the red eyes of the embryo are very conspicuous. (Fig. 1F, ES.)

Dimensions: Length 0.31-0.38 mean 0.35 mm. (20 eggs).

Nymphal Instars (Fig. 1A-E).

Insect approximately oval; dorso-ventrally flattened; with an entire marginal fringe of setae from which arise clear, brittle filaments which lengthen as the instar matures; the number of marginal setae increases at each instar. These setae and filaments may also be present on the dorsal surface; the 1st and 2nd instars always bear dorsal setae (Fig. 1A and B), but the 3rd, 4th and 5th instars may possess a small number, a large number (Fig. 1D) or be entirely free of dorsal setae (Fig. 1C and E); the filaments may be of regular or irregular lengths; in first and second instars they may equal half and in later instars a third the length of the nymph; they are cast at each moult and grown anew. Ventral surface with scattered hairs. Antennae with sensoria and two conspicuous spines at the apex; they are light in colour, with brown apices in all except the 1st instar. Eyes red turning to grey in the 5th instar. Rostrum pale with brown apex. The wing-pads as they develop are anteriorly produced uniting with the sides of the head until in the 5th instar they extend more than half way towards the apex of the head. Before the final ecdysis the anterior wing-pads shrink, leaving the outer cuticle empty as far as the basal margin of the head (Fig. 1E). Tibiae bear near the apex a long spine with an incurved clubbed tip, tarsi have fan-shaped empodia; legs are pale with brown tarsi in the later instars. The 1st instar has a single row of anal pores, the second and later instars a double row.

The nymphs are shining and semi-transparent when newly emerged, clouding and thickening towards the end of each instar. The 1st and 2nd instars are pale yellow or orange, but some darker individuals appear in the 3rd instar, and the 4th and 5th instars vary a great deal in colour, containing nymphs of a pale greenish blue, also white, yellow, orange, orange with brown mottlings (these latter having dark wing-pads, a dark median line down the head and thorax to within a short distance of the posterior-lateral margin of the abdomen) and uniform dark brown individuals.

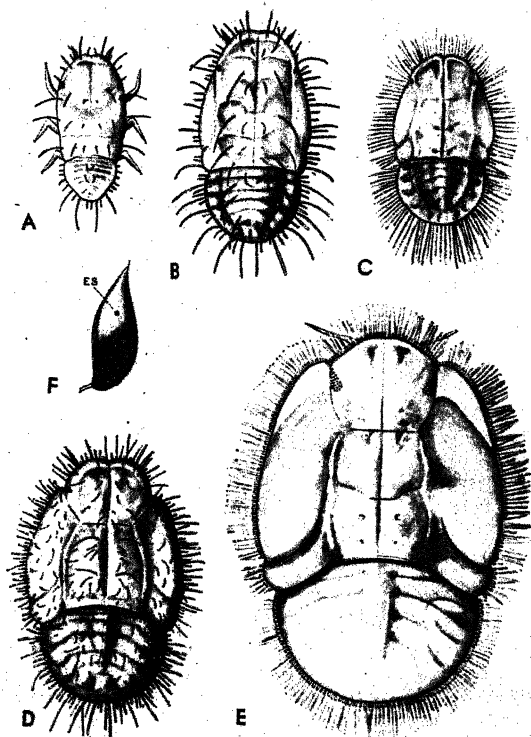


FIG. 1.—A. First nymphal instar.

B. Second instar.

C. Third instar.

D. Fourth instar.

E. Fifth instar.

F. Egg (ES shows eye spot of embryo)

A, B and D show variety with dorsal setae.

C and E show "naked" variety.

Approx. x 80

" x 80

" x 40

" x 40

" x 40

" x 80

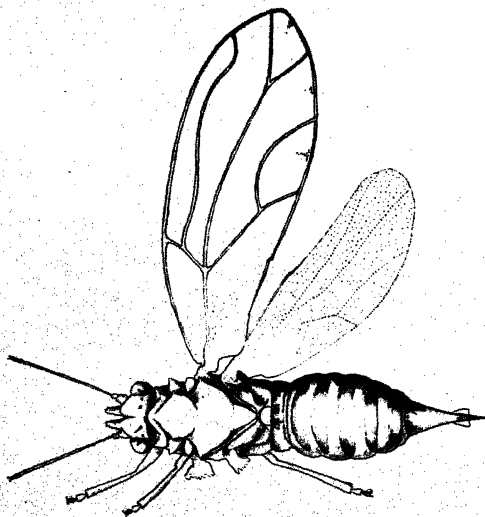
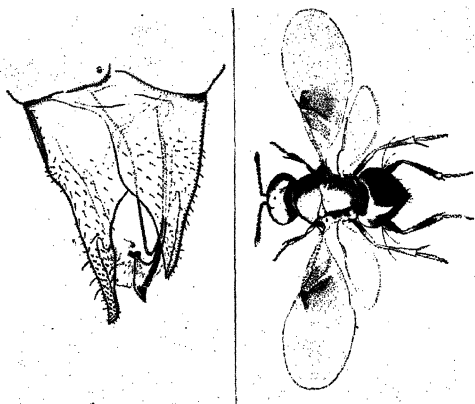


FIG. 2.—Bottom—Adult female, *P. vitreoradiata*.
Top left—Female genitalia of below.
Top right—Encyrtid parasite.

As a general rule those nymphs feeding on the upper surface of the leaf are darker in colour than those on the under surface. This is particularly noticeable in 5th instar nymphs, the dark orange and brown varieties being found on the upper surface, those on the undersurface being mainly white, greenish-blue, or pale yellow. The darker forms from the upper surfaces are nearly always without dorsal setae, while the pale forms on the undersurface are densely clothed and often hardly distinguishable from the pale tomentum of the leaf.

TABLE I. KEY TO NYMPHAL INSTARS

	Antennae.	Wing-pads.	Anal Pore-ring.	Length in mm.*	Width in mm.*
1st Instar	2-jointed	Absent	Single row of pores	0.32-0.41 Mean 0.38	0.17-0.21 Mean 0.19
2nd Instar	2-jointed	Visible but Narrow	Double row of pores	0.52-0.59 Mean 0.54	0.28-0.33 Mean 0.31
3rd Instar	3-jointed	Clearly defined	"	0.72-0.86 Mean 0.80	0.45-0.52 Mean 0.49
4th Instar	4-jointed	"	"	1.14-1.24 Mean 1.20	0.76-0.86 Mean 0.80
5th Instar	6-jointed	"	"	1.76-2.00 Mean 1.89	1.21-1.35 Mean 1.28

* 20 individuals measured for each instar, measurements exclusive of filaments.

LIFE CYCLE AND HABITS

Method of rearing nymphs

The most satisfactory type of cage for rearing Chermids was found to be a small wire gauze one which was attached to the leaf by means of round elastic and a cork (Fig. 3). The cage was cylindrical, a curved strip of brass gauze $\frac{3}{8}$ in. wide forming the sides, while the top consisted of a circle of the same material $\frac{1}{8}$ in. in diameter lightly soldered into position. A small rim of plasticine was used to cover the rough edges of the gauze and to ensure a perfect seal on to the leaf, which was essential with nymphs so small and flattened. Nymphs on hatching were moved to individual cages with a camel-hair brush and examined daily.

For field experiments with adults the gauze cages were found to be satisfactory, but for rearing nymphs they possessed the following disadvantages:—

(1) The cages could be attached only to leaves sufficiently mature to bear the weight of the cage; this meant that the leaf hardened before the life cycle of the nymph was complete and at least once during its life the nymph had to be removed to a younger leaf.

(2) The cages prevented the satisfactory examination of the nymphs and repeated removal of the cage reduced the efficiency of the plasticine seal.

(3) If exposed to the sun in summer the wire gauze became very hot and the caged insects died.



FIG. 3.—Gauze cage used in experiment. Photo: L. H. Wright
Foliage showing characteristic pitting.

For later experiments the cages were discarded and each nymph was isolated upon a shoot from which all other individuals and eggs had been removed. These shoots were labelled and all neighbouring foliage cut away. Nymphs were placed in position with a camel-hair brush. Observations were made daily with the aid of a hand lens and the growth recorded. There was little chance of the shoots becoming reinfested except from adults and any eggs that were found were removed. When the nymph was expected to emerge a gauze cage was placed over it and the adults secured.

Eggs

The eggs laid per female for 12 caged individuals ranged from 67 to 415 eggs, with an average of 192.

The eggs were laid in batches of up to 50 on the undersurface of the young leaves, or, if these were not available, on the unopened buds. The eggs were set obliquely on the leaf, embedded in the tomentum and attached by the short stalk.

The incubation period was 11-14 days, with an average of 13 days.

Nymphal Instars

TABLE II. DURATION OF NYMPHAL INSTARS

Instar.	Duration in Days.	Most Frequent Number of Days.	Number of Individuals.
1	6-21	13	136
2	5-12	7	82
3	3-13	7	59
4	4-18	6	55
5	6-15	12	30
Total :		45	

Table II shows that only 30 individuals completed their 5th instar. This was due to a high mortality and also to some of the small nymphs becoming lost. These 30 Chermids completed their nymphal period in 38-58 days, with an average of 45 days.

The total of the days most frequently taken for each instar for all the nymphs recorded in Table II was also 45 days.

Nymphs were reared during the months of June to December and the variation in length of life-cycle did not seem to be the result of the time of year. The condition of the host leaf, however, seemed to be important, development being slower on older leaves. Owing to lack of suitable foliage nymphs could not be reared from January to March.

At hatching, the young nymph forces itself head first through the thin membrane at the apex of the egg. The newly emerged nymph may crawl for several hours before finally settling down on either the upper or undersurface of the leaf, where a characteristic pit is gradually formed.

Adults

Length of life under natural conditions could not be determined, but for 17 caged adults ranged from 20-90 days, with an average of 42 days.

Pre-oviposition period for 17 females ranged from 5-38 days, with an average of 11 days.

The adults are very active and appear to jump rather than fly. The antennae are never still and maintain an agitated up and down motion; the whole body is continually flicked from side to side.

Both adults and nymphs excrete large quantities of wax-covered honey-dew.

SEASONAL HISTORY

Methods of estimating Chermid population

Weekly counts were made on each of seven small *P. crassifolium* trees from 11th September, 1942 to 26th February, 1945 (except for the period late November, 1943 to March, 1944) to ascertain the seasonal abundance of Chermids throughout the year. The trees were the same age and size. The whole of each tree was examined leaf by leaf for Chermids. Records were kept only of the number of 5th instar Chermids; these were readily distinguishable macroscopically and easily separable from other instars. No counts of adults were made as caging the trees would have created unnatural conditions.

As it was thought that the condition of the foliage might influence the seasonal abundance of the insects, notes were taken on the condition of the individual trees throughout the experiment.

Counts were taken of the number of predators present.

Results

Chermids were found to be present throughout the year, being most abundant in spring and autumn. As fluctuation in the population followed similar curves for each of the seven trees, results are shown as total weekly counts on all the trees (Fig. 4).

Predators were present during most of the year, being most abundant in July and August after the peak in the Chermid population (Fig. 5).

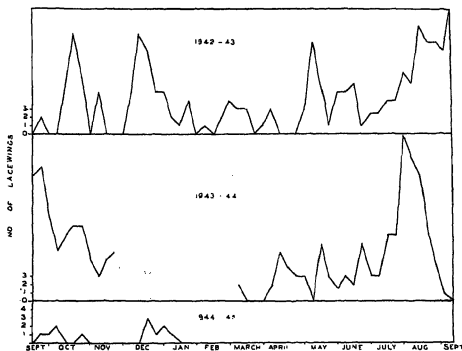


FIG. 5.—Graph showing number of *D. binocularis* recorded on the seven trees.

DISCUSSION

Chermids are present throughout the year and given favourable conditions would be capable of producing five generations annually as the period between one generation and the next is on an average 69 days. (incubation 13 days, nymphal stages 45 days, pre-oviposition 11 days). It is therefore clear that the two major peaks do not simply indicate that two generations are produced annually.

The major factor responsible for the fluctuations in the Chermid population was found to be the availability of suitable foliage. This can be clearly seen by comparing Fig. 4 with Table III. New growth in the spring and autumn resulted in an increase in the Chermid population; when the foliage hardened, the population declined.

The second factor was the presence of lacewing predators. When Fig. 4 is compared with Fig. 5 it will be seen that the lacewing population increased after the peak in the Chermid population, and that the absence of lacewings did not result in a major increase in Chermids. The direct influence of the lacewings is discussed later, but comparison will show that it was the foliage condition rather than the predators which induced the fluctuations in the number of Chermids.

The long life of the adult Chermid is important as it enables foliage to be infested as soon as it appears. It is also a factor in bridging the gap in the summer between the main growing periods of the trees. New growth is recorded in January, but except for isolated shoots in the shade, this hardened so rapidly that Chermids could not complete their development and ultimately died, so that no resulting increase is shown in the Chermid numbers in Fig. 4. A small number of Chermids matured on the shaded foliage, and, together with adults which had survived the

summer, infested the new growth which appeared in March. Although no counts were made in 1944, over this period, it can safely be assumed that no major increase would have occurred.

An initial increase in the Chermid population resulting from the sprouting of new growth is indicated on the graph after approximately 33 days, the time required for nymphs to reach the 5th instar (Table II).

The counts for September-October-November in 1943 and 1944 did not attain the high figures of the previous year. This was partially due to the foliage not being as suitable because the season was hotter, but may also have been caused by the presence of a larger number of predators in August.

The predators were present during most of the year (Fig. 5), but their occurrence was too erratic to be effective as a control, particularly as the Chermids are capable of building up a large population in a short time. The effect of the lacewings on the Chermid population was not very apparent except over the August-September period. At this time the lacewings had reached a peak, following the peak in the Chermid population, and the Chermids consisted only of very young nymphs which were hatching on the new growth. From the section on predators where their food requirements are discussed, it will be seen that feeding on young instars only, about three times as many Chermids are required as when feeding on the larger stages. Thus the large number of lacewings feeding on very young Chermid nymphs in August, 1943 and 1944 reduced the potential 5th instar population of September, 1943 and 1944. For example, the number of freshly hatched Chermid nymphs destroyed by twenty lacewings recorded at the beginning of August, 1944 could be estimated at over 6,000. Even allowing for a high mortality rate this would give a figure for the 5th instar population of September comparable with that of 1942. No records are available for August, 1942, but as the trees had only been planted a short time it is not unlikely that predators had not then appeared in any number. It will be noted that when the lacewing population dropped at the end of August, 1944 owing to lack of food, the numbers of Chermids started to build up again immediately.

Lacewings present during the summer had little effect on the 5th instar population, because they fed mainly in the terminal shoots and therefore destroyed only those nymphs which in any case would not have reached maturity.

It seems clear that given suitable foliage and freedom from predators the Chermids would be capable of building up and maintaining a large population throughout the entire year, but under Auckland conditions are only likely to do so during the spring and autumn.

NATURAL ENEMIES OF CHERMIDS

PREDATORS

Neuroptera

Three lacewings were observed to be predacious on *Powellia viticordata*, these being:—

1. *Drepanacra binocular* Newmn.
2. *Micromus tasmaniac* Walk.
3. *Boriomyia maorica* Tillyard.

Of these *Drepanacra binocular* was by far the most abundant. Larvæ of this lacewing were first observed when Chermid counts were commenced. Records were made of those observed to ascertain to what extent the lacewing acted as a control (Fig. 5). Notes on the life history were made and details of the food requirements were recorded.

Very few adult lacewings were observed in the field and no counts of these were made. Adults reared in the laboratory fed readily on Chermid larvæ and adults, but no details were recorded of their food requirements.

Life History of Neuroptera

Length of the life cycle from egg to adult for specimens reared in the laboratory was 27-30 days, incubation period being 6 days, larval period 9-11 days and pupal period 11-14 days.

None of the lacewings bred through to the adult stage in the laboratory laid eggs, but one fertile female taken in the field laid 182 eggs between 21st October and 27th November.

The food requirements for five larvæ were obtained by placing the larvæ in separate dishes on hatching and feeding them continuously with nymphal Chermids. Details of the total consumption were as follows:—

No. 1.	Hatched	----	1st October, 1942.
	Pupated	----	10th October, 1942.
	Total consumption		134 4th instar Chermids.
No. 2.	Hatched	----	1st October, 1942.
	Pupated	----	12th October, 1942.
	Total consumption		(96 1st instar Chermids.
Total 232			(52 2nd " "
			(60 3rd " "
			(24 5th " "
No. 3.	Hatched	----	1st October, 1942.
	Pupated	----	10th October, 1942.
	Total consumption		77 5th instar Chermids.
No. 4.	Hatched	----	27th October, 1942.
	Pupated	----	6th November, 1942.
	Total consumption		88 5th instar Chermids.
No. 5.	Hatched	----	25th October, 1942.
	Pupated	----	5th November, 1942.
	Total consumption		118 4th instar Chermids.
			(on hatching No. 5 also consumed a number of eggs of its own kind)

Adult lacewings reared in the laboratory were comparable in size with adults from the field and provided there was an adequate supply of food in the field, total consumption in the laboratory should be comparable with that in the field.

From these results it can readily be seen that the lacewings would exercise a noticeable control on the Chermids particularly when feeding on the young stages, and their effect as a whole is mentioned in the Discussion.

Micromus tasmaniae was present mainly during the summer months and was at no time abundant.

Only three larvæ of *Boriomyia maorica* were obtained during the whole period of investigation.

Coleoptera

During the summer months *Coccinellid* larvæ were occasionally found destroying nymphal Chermids; one of these was bred through and proved to be *Orcus chalybeus* Bd. Adults of this species were also discovered

feeding on the Chermids and were observed to lay their eggs on the *Pittosporum* trees.

Arachnida

Small spiders were frequently observed in webs at the apex of *Pittosporum* shoots feeding on both nymphal and adult stages of *Poecilia vitreoradiata*.

PARASITE

One internal parasite was bred from *P. vitreoradiata*, this being a small Chalcid wasp, family Encyrtidae (Fig. 2 bottom right). Five 5th instar Chermids which had been parasitised were taken in the field in August, 1943, and each nymph contained one Chalcid larva inside the extended skin. The larvæ pupated and approximately two weeks later adult Chalcids emerged inside the Chermid skins, where they remained for a day before biting their way out through a hole in the dorsal surface of the abdomen of the host. In all cases the parasite pupated with the head pointing towards the posterior end of the host.

This parasite was apparently not common as the five specimens were the only ones noticed over the whole period of the Chermid counts.

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AN IMPROVED RADIAL DISTRIBUTION FUNCTION AND EQUATION OF STATE.

By A. G. McLELLAN, University of Otago, Dunedin

An approximate equation of state has recently been derived by A. E. Rodriguez (1, 2). This derivation involves a method of linearising the non-linear integral equation for the radial distribution function $g(r)$, obtained by Born and Green (3),

$$\log_e g(r) + \frac{\phi(r)}{kT} = \frac{n_1 \pi}{kT r} \int_0^\infty \int_{-r}^r (s^2 - t^2) (t + r) [g(t + r) - 1] dt g(s) \phi'(s) ds \quad (1),$$

where n_1 is the number density and $\phi(r)$ the potential energy of two molecules at a distance r apart. Rodriguez used the potential energy function of Lennard-Jones (4), which is also used in the work described later. With several approximations, he obtained isotherms of argon at two temperatures, 130°K and 150°K (the critical temperature). However, the theoretical curves do not give good agreement with experiments. A more accurate solution of (1) is therefore desirable. The present note describes a new method of solution.

A function $f(r)$ is defined by

$$g(r) = [1 + f(r)] e^{-\phi(r)/kT} \quad (2).$$

From experiments on X-ray diffraction in liquids $f(r)$ is known to be small for $r > 1.5r_0$, r_0 being the value of r for which $\phi(r)$ is a minimum. For convenience in later calculations, $f(r)$ is represented by a polynomial $\sum c_i r^i$ for $r < 1.5r_0$ and zero elsewhere. In evaluating the

inner integral of (1), the factor $e^{-\phi(r)/kT}$ in $g(r)$ is also represented by a polynomial in the interval $\alpha < r < \beta$, zero for $r < \alpha$ and 1 for $r > \beta$; the values of α and β can be assigned for a given temperature with considerable accuracy. Such approximation is not valid in evaluating the outer integral of (1) because the factor $e^{-\phi(s)/kT}$ in $g(s)$ is multiplied by $\phi'(s)$ which is strongly negative in the neighbourhood of $s = \alpha$. With these approximations the equation can be integrated explicitly. The result is an equation in the c_i of the form

$$\log_e(1 + \sum_i c_i r^i) = \frac{n_1}{n_0} \left\{ \gamma(r) + \sum_i A_i(r) c_i + \sum_{i,j} c_i c_j B_{ij}(r) \right\} \quad (3),$$

where the coefficients on the right hand side are functions of r , and n_0 is the number density of crystal argon. By assigning as many values of r as there are c_i 's a system of equations for the c_i 's is obtained.

As a first approximation this equation can be solved by linearising and neglecting all terms on the right hand side involving the c_i thus yielding:

$$f(r) = - \frac{n_1}{n_0} \gamma(r) \quad (4).$$

A better approximation is obtained by neglecting terms quadratic and higher in the c_i . Finally the complete equation (3) can be solved by successive approximations, commencing with small values of n_1/n_0 and increasing this quantity by small amounts until the density of crystal argon has been reached.

The first approximation (4) has been evaluated for argon at two temperatures 120°K and 150°K, and the corresponding isotherms calculated using the equation.

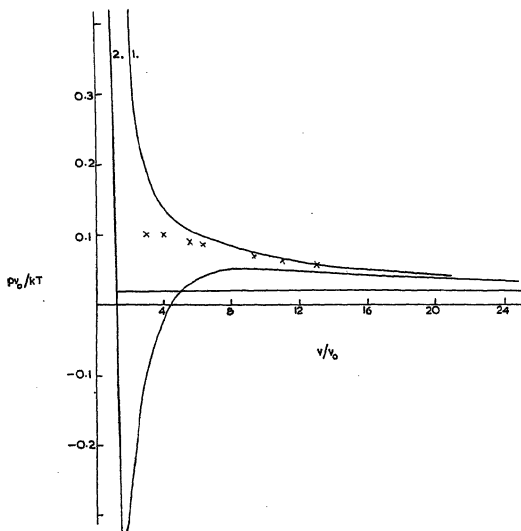
$$p = n_1 kT - \frac{2\pi}{3} n_1^2 \int_0^\infty g(r) \phi'(r) r^3 dr \quad (5).$$

These together with an isotherm observed at 151.9°K (5) are shown in the accompanying figure. They are given in terms of $p v_0/kT$ and v/v_0 following Lennard-Jones and Devonshire (6), v_0 being the volume per molecule in crystal argon at absolute zero, and v that in the fluid. It can be seen that this approximation will give a critical isotherm at a temperature slightly less than 150°K. Using the results of the calculations at 120°K and 150°K, the critical data have been obtained by linear interpolation and are shown in Table I, where they are compared with the observed data.

TABLE I.

	T_c °K.	Critical Density. gm/cc.	P_c Atm.	$P_c V_c / kT_c$
Calc.	140	0.40	46	.333
Obs.	150.7	0.531	48	.292

The densities of liquid and vapour and the pressure in the liquid-vapour region at 120°K have been derived from the calculated isotherm by applying Maxwell's law of equal areas. These are shown and compared with values obtained from experimental data in Table II.



ARGON ISOTHERMS.

x Experimental, $T = 151.9^\circ\text{K}$, (1) Calculated, $T = 150^\circ\text{K}$.
 (2) Calculated, $T = 120^\circ\text{K}$, showing the saturated vapour phase.

TABLE II.

	S.V.P.	Liquid Density.	Vapour Density.
	Atm.	gm/cc.	
Calc.	8.3	1.50	0.041
Obs.	12.2	1.158	0.061

Although approximation (4) is not an accurate solution at 120°K where high densities must be considered, the isotherm derived from it is in closer relative agreement with experiment than that previously obtained by Rodriguez at 130°K .

Work is in progress on the higher order approximations at these two temperatures and initial results are promising.

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NOTE ON A LABORATORY EVAPORATOR

By N. W. VERE-JONES, Chemical Engineering Section, Dominion
Laboratory, Department of Scientific and Industrial Research,
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Summary

An evaporator, suitable for the vacuum concentration of extracts of biological origin, is described.

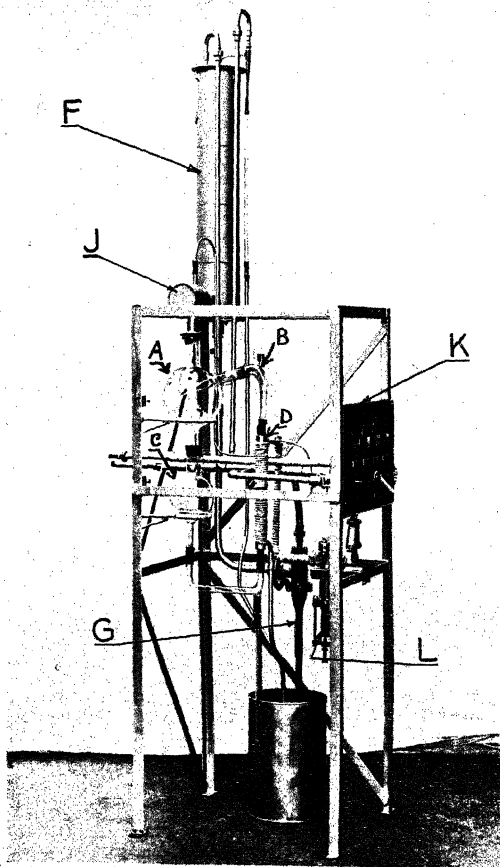
INTRODUCTION

The evaporation at low temperature of relatively large volumes of aqueous or other extracts often presents difficulty. If of biological origin, frothing may be troublesome; as the liquid becomes concentrated and viscous, heat transfer is reduced, local over-heating may result, leading to severe bumping and destruction of thermolabile substances.

The purpose of this note is to make better known a simple but effective apparatus for overcoming many of these difficulties. It may readily be constructed from standard laboratory equipment to evaporate as much as 20 litres per hour.

DESCRIPTION OF APPARATUS

The accompanying figure illustrates the apparatus. The evaporator, A, is made from an ordinary laboratory flask (that illustrated is of five-litre capacity), into which is inserted a vapour pipe, B. This may conveniently be done by welding a "Quickfit" socket to the wall of the flask and inserting therein a "Quickfit" plug carrying a tube. To the bottom of A is welded a glass tube connecting to another flask, C, which acts as a reservoir for the concentrate; the size of C should be determined by the volume of liquid to be concentrated and the concentration required. When the final volume of concentrate is small, C may be omitted and the tube from the bottom of A connected directly to the heating tube, or calandria, D. When C is required, a tube is welded to its bottom and connects with D. An alternative is to take this tube from the side of the neck of C, which then becomes a "salt box," a convenient arrangement when much solid matter is thrown out of solution during the evaporation, D consists of a steam-jacketed tube;



for many purposes a silver tube is most convenient, though stainless steel, silver-plated copper, or glass are practicable alternatives. The heating tube connects directly with the vapour pipe entering A. A "tee," for the introduction of the feed, is inserted between C and D. The neck of A connects with a condenser and vacuum pump. Some form of splash head is advisable between evaporator and condenser to separate entrained liquid from the vapour.

When the apparatus is under vacuum, liquid to be concentrated is sucked into the apparatus until it reaches a convenient height in A, usually one or two inches above its bottom outlet. Steam is admitted to the jacket of the calandria and causes rapid boiling in D. A slug of liquid and vapour is ejected at high velocity against the wall of A. This action very effectively breaks up any foam in A, the effectiveness of the action depending on the level of liquid in A and, particularly, on the distance between the end of the vapour pipe and the wall of the flask: 5 millimetres to 10 millimetres is generally satisfactory. Liquids otherwise impossible to distil under vacuum because of excessive foaming have been successfully concentrated in this type of apparatus. Feed is continuously admitted to maintain the liquid level in A.

With a silver-plated copper heating tube an apparent overall coefficient of heat transfer of 750 B.Th.U., hr./sq. ft./°F. temperature difference can be expected. From this figure the size of heater appropriate for a required evaporation may be calculated. The one illustrated is 15 inches long and 1 inch in external diameter, and will evaporate three gallons per hour at a temperature of 35° C. For high rates of heat transfer, the tube should have a highly polished surface; in spite of its lower conductivity, glass may be found to have a higher overall coefficient than a rough metal tube owing to the high film coefficients of the latter. The heat transfer figure quoted is higher than that normally found in modern commercial evaporators which employ natural circulation, though lower than the maximal figures which have been attained with forced circulation. Not only will high heat-transfer rates reduce the duration of the evaporation but they will give rise to a rapid pumping action in the apparatus and thus reduce the time during which the liquid is in contact with the heated surface and so restrict damage to thermolabile substances.

The apparatus was designed and fabricated by the Chemical Engineering Section of the Dominion Laboratory for the evaporation of grass extracts at the request of the Department of Agriculture's Animal Research Station, Ruakura. A spray and perforated plate condenser, F, is used; as vapour and cooling water are in direct contact, this is efficient but impermissible when the distillate is required. Condensed vapour and cooling water are discharged against atmospheric pressure by a water-operated jet pump, G. Air and other non-condensable gases are ejected from the top of the condenser by another jet pump, J is an entrainment separator with connection to a vacuum gauge. This type of equipment has the advantage of requiring no vacuum pump or other moving parts, but the mechanical efficiency is low. For the evaporator, described, approximately 800 gallons of water per hour are required for the condenser and ejectors, with cooling water at 65° F. If a surface condenser had been used, this alone, if of a reasonable size, would have required about 300 gallons of water per hour at 65° F. to evaporate an aqueous extract at a temperature under 100° F. For lower temperatures of evaporation, special condensing and vacuum-producing apparatus

would be necessary. The control panel, K, has valves and gauges for control and measurement of vacuum, steam, and water pressures to the condenser and to the ejectors.

In laboratories where steam is not available as a service, a tin can will form an adequate boiler, as steam above atmospheric pressure is not required. The pressure of service steam would require reduction to below five pounds per square inch gauge (L in figure), or back-surfing in the apparatus will probably occur. This surging is also affected by the height of the liquid level in the apparatus relative to the top of the heating tube; increasing this height reduces the tendency to surge, but only at the expense of an elevation of the boiling point due to the resulting static head. With a vacuum of 29 inches of mercury, this rise in boiling-point will be about 18° F. for a static head of 12 inches.

For small rates of evaporation (e.g., of the order of one liter per hour), silver tubes of 5 millimetre bore and a few inches in length will be found satisfactory, with a corresponding reduction in size of the other parts of the apparatus.

ACKNOWLEDGEMENT

Appreciation is expressed to Mr. F. J. T. Grigg, Director of the Dominion Laboratory, for his interest and permission to publish this note.

A LABORATORY WET MAGNETIC SEPARATOR FOR STRONGLY MAGNETIC MINERAL SANDS

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Summary

A laboratory-size separator is described in sufficient detail to enable interested parties to reproduce it. Feed arrangements for both wet and dry sands are given. With a nominal through-put of 280 pounds per hour to give a commercial grade concentrate, the separator is capable, at reduced capacity, of yielding an exceptionally high-grade uniform concentrate.

INTRODUCTION

This separator was built primarily as a means of obtaining several hundredweights of Taranaki ironsand for some technical scale work on a titanium and vanadium extraction process for a New Zealand University thesis; reproducible samples that would be representative of the highest commercially economic grade of concentrate were required. While experimenting with the machine to decide what might be a commercial concentrate, it became evident that the machine, if further developed, would be a very useful apparatus for the magnetic assessment of New Zealand ironsand deposits. It has been satisfactorily developed to such a stage. It has proved capable of rejecting practically all hybrid, magnetic mineral-gangue particles, to give what appears under the microscope to be a clean sample; in other adjustment it will give a reproducible sample containing these hybrid particles. It is suitable only for ferro-magnetic materials; an attempt was made to separate ilmenite sand using the maximum power that the magnet would stand (40 Volts 1640 Watts for a short period), but without success.

Though magnetic separation is a standard ore-dressing process, no information could be obtained as to whether or not a suitable machine was available in New Zealand other than an experimental model constructed by Officer¹ in connection with a thesis dealing with the magnetic separation of weakly magnetic sands. However, a perusal of Officer's paper showed that the machine was entirely unsuited for the purpose in hand, as a prerequisite for its successful working was that magnetite must be removed from the sample. It operated on the principle that a series of magnetic particles passing through a homogeneous magnetic field with other than parallel boundaries are dispersed according to their mass susceptibility, being refracted at those boundaries somewhat analogously to the phenomenon of the refraction of light at a boundary. A magnetic particle does not experience a force in the direction of a homogeneous field; but in practice such a field cannot be obtained, so that there is also a force urging the particles towards the poles as they pass through the field. In the case of weakly magnetic particles, this force is small compared with that of gravity urging them through the field, so the particles pass through successfully. With ferro-magnetic materials, including magnetite, this force is too great to allow the particles to pass through without travelling to and fouling the pole pieces, thus effectively stopping the machine.

It was decided to devise and construct a machine that would deal with the strongly magnetic "iron sand." A search of the technical literature and catalogues showed that many types had been invented, but

no details were available about any of them. The most helpful review was found in Perry's *Chemical Engineers' Handbook*², in which the two main classes of separator were discussed—viz., wet and dry types; it stated that experience had shown that the wet type was greatly superior to the dry type in through-put and efficiency when it was required to separate large quantities of approximately equally proportioned components.

OPERATING PRINCIPLES

(Ref. Fig. 1.)

Dried sand to be separated, after having been coarse-screened to remove any extraneous rubbish such as sticks, large stones, or shells, is fed by means of a hopper on to a rubber belt moving up grade over the surface of an electro-magnet. Running down grade, at a velocity determined by the grade, is a copious sheet of water directed from a fish-tail jet just within the field of the electro-magnet. In the absence of a magnetic field, all the sand fed on to the belt is carried down grade by the water and is discharged into a chute at the lower end. In the presence of a suitable magnetic field, magnetic material suffers an attraction towards the magnet, and so has its gravitational force against the moving belt supplemented by an amount proportional to the strength of the field and the magnetic susceptibility of the material. By applying a suitable field for a given material, this supplementary force can be increased to a point where frictional drag between the moving belt and the particle is sufficient to carry it up against and out of the water stream. By referring to Fig. 5, the construction of the pole shoes will be seen to be in a series of alternate diamond-shaped pieces of mild steel. The rows have alternate polarity and produce zigzag field concentrations, both across and along the magnet. Magnetic particles being dragged up against the water stream are thus rolled about on the belt, and so expose to the scavenging action of the water stream any non-magnetic particles occluded by them. Also, fine particles immersed in water do not tend to aggregate to the same extent as they do when damp. In Fig. 4—a photograph of the separator stationary, but with its magnetic field effective—the zigzag paths are clearly indicated by magnetic particles which have been concentrated along them. Under running conditions, the speed of the process does not allow such clearly defined congregation along these paths, and the paths are broadened out to about half the effective width of the belt; the magnetic particles can be seen moving from side to side as they are carried up against the water stream.

CONSTRUCTION

From experiments conducted with both wet and dry sand, it became apparent that simple physical properties other than magnetic must be considered, as some exerted a critical influence on the design of a separator of the size proposed. The following were noted:—

- (a) In the sample available, taken by A. D. Monro as representative of the Patea beach sands, most of the constituents were of the same order of density and sank rapidly against a fairly fast up-flowing current of water.
- (b) That the sand was of very even grading. When a raw beach sample (some 200 pounds) was put through screens, only 6 pounds was retained on a 22 mesh, and most of that residue was shell remnants and driftwood.

- (c) That perfectly dry sand flowed very freely and that practically the whole contents of a container of screened (22 mesh) sand would rapidly run out through a quarter-inch diameter hole in the bottom without blocking.
- (d) That damp sand (i.e., sand retaining only excess water after draining) would not flow at all. When in a heap about 12 inches high, some of the sand was removed at the base, the angle of

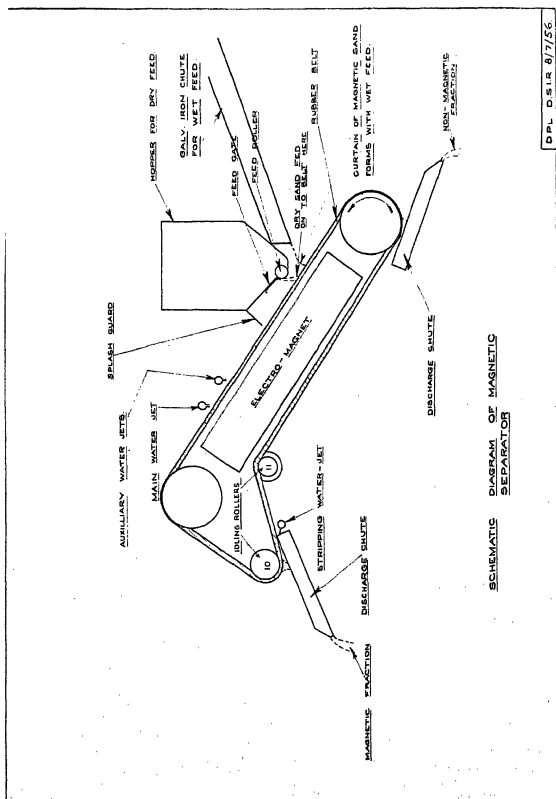


FIG. 1.—Schematic line diagram of the separator.

but required a copious flow of water directed from above to remove it efficiently.

- (f) As seen under the microscope, carefully hand-separated "iron sand" consisted mainly of homogeneous black particles of rounded form and of remarkably regular size, but also contained a considerable proportion of particles that were partly "iron sand" and partly some other mineral. In the beach sands, such particles abound, and a factor of importance was to devise an apparatus by which the true ironsand would be effectively separated from the weakly magnetic minerals accompanying it without including too great a portion of such composite grains.

These simple and apparently obvious facts have been listed rather fully to draw the attention of any future designer of such a separator to them, as the writer is convinced that if not given major consideration at design stage, the effects could easily bring about failure of a machine that was magnetically satisfactory. For instance, illustrating (*c*) and (*d*), once during the operation of the machine, hereafter described, it was stopped with a full hopper of dry sand without first turning off the water supply to the top jets (see Figs. 1, 3, and 4). A small trickle of sand ran out from the clearance left for mechanical reasons at the end of the feed roller. When the sand touched the wet surface below, it was immobilized and not swept away by the water, as the magnetic field was functioning. It immediately built up into a pile until the gap between the wet belt and the hopper was effectively bridged. Water then travelled up this pile by capillarity and damped the sand in the bottom of the hopper before the machine was restarted.

The machine could not be made to function again until the sand and hopper had been removed and thoroughly dried. An attempt was made to clear it by opening the feed gate (Fig. 5) to its full width of half an inch and poking the sand down from above with a rod, but without success. Only after dismantling and thoroughly drying the hopper could sand be made to go through it.

The magnetic separator illustrated in Figs. 1 and 2 and depicted in Figs. 3, 4, 5, and 6 was devised and proved very satisfactory in use. It was constructed mainly of standard steel sections and electrically welded where possible. As constructed for sampling work to be fed with dried sand, it consisted of—

- (1) A galvanized steel tray to catch the water dripping from various points of the machine when working and to allow of its recirculation.
- (2) An angle-iron base with two vertical plates welded to one end and a suitable anchorage for turnbuckle (5) to the other end.
- (3) A cradle frame with plates welded as illustrated to provide suitable fixtures for bearings and spindles of the four belt rollers. This frame was pivoted on two brass screwed and hexagonal flanged bushes (4), which were secured by suitable nuts, and its inclination to the base plate (2) was adjusted by means of the stout turnbuckle (5).
- (4) Two pivot bearings turned from hexagon brass section and concentrically bushed with phenol formaldehyde plastic bushes, to serve as water-lubricated bearings for the driver roller shaft.
- (5) A turnbuckle consisting of a long hexagon rod threaded both left and right hand at the ends, and relieved below the depth of the

thread for the middle half of its length; and two oppositely threaded steel eye-bolts and lock-nuts.

- (6) and (7) Two flanged belt pulleys, (6) being the driving pulley and (7) the idler, fabricated from brass tubing and plate-brass ends and fastened by sweating with soft solder. Bosses were easy-flowed to the flange plates before assembly and boring; the torque was transmitted from the shaft by means of two tapered pins—one through each boss.
- (8) Two adjustable bearing blocks of phenol formaldehyde (bakelite resin) with a square milled on a round section, thus leaving a retaining flange just visible above the retaining cage which consisted of a steel section welded to cradle frame (3).

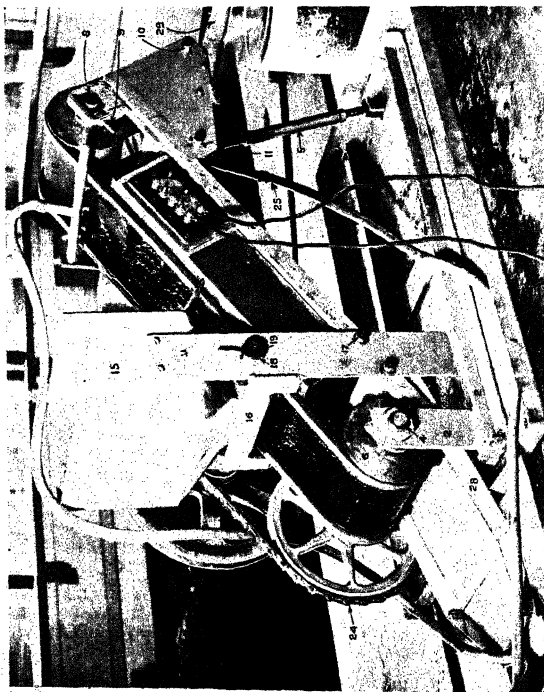


FIG. 3.—General view of separator set up for dry-sand feed.

- (9) Two adjusting screws and lock-nuts by means of which the bearings (8) could be adjusted up to three-fourths of an inch of travel to give correct belt tension and alignment of the idler pulley, so that the belt would not climb up on the flange plates. This latter adjustment was very critical, but, once obtained, quite satisfactory.
- (10) and (11) Not visible in the photograph, but shown in Fig. 1 are two belt idler rollers. They were constructed from brass tubing with ends turned from solid bar and soft-soldered in. They were suitably bushed with phenol formaldehyde bushes for bearings, as the shafts were stationary. It will be noted that (11) operated on the opposite surface of the belt to the other rollers and was made as a stepped cylinder to accommodate and support the side runners of the belt.
- (12) A fabric reinforced rubber belt was moulded from sheet rubber and soft three-eighths of an inch by half an inch rectangular rubber sections. It will be seen to have raised edges in the form of three-eighths of an inch by half an inch strips moulded to the edges of the flat portion. These strips performed the double duty of preventing the water stream and sand from spilling over, and also gave the necessary location of the belt during its reflex running over roller (11). It will be seen that the belt was made to conform to a path which may be likened to the outline of a boomerang. In this way four surfaces or two ends of an endless path were obtained from which water would drain by gravitation, and so enabled the two sand fractions to be washed from the belt, despite their clinging tendencies, without carry-over. This belt path was realized to be the critical feature of the design with no alternative; and some misgivings were entertained as to whether a suitable belt could be made locally that would be sufficiently uniform not to climb and sufficiently strong and elastic in the side runners and their vulcanizing to withstand the excess compression of inflexing over the roller (11). An analysis of the strains and stresses in the side runners and in the adjacent belt section in passing over the roller (11) shows a very complex situation.

In the middle portion of the belt, flexing is normal, but at the edges, because of the fabric reinforcement, the top surface cannot stretch as it runs over the rollers and the flexing compresses the runners about this top surface as the neutral axis; further, the friction due to the belt loading against the step of the roller tends to prevent strain due to the above compression and must give rise to high stresses; to relieve the steps of the roller so that the runners would not be supported would make the situation worse rather than better in that the unsupported edges would tend to shear off. However, the belt as delivered was very successful. The requirements of the belt have been discussed at length, so that if an attempt were ever made to scale the machine up to larger size, the problem presented could be anticipated. In such a case, if an extruded or moulded belt were formed in the section of a shallow U with the sides of similar thickness to the belt, a technique could possibly be devised for the sides to flatten in passing over the inverting roller, which could be a plain cylinder.

- (13) An electro-magnet secured by four studs to the cradle frame —(3) and Fig. 2—shows the manner of its construction and assembly. As water continually flows over it, it had to be fully watertight as a unit, or else the low resistance paths presented would have caused rapid electrolytic corrosion, even if between turns insulation had not broken down. After standing immersed under 2 feet of water for a week, the lowest earth test recorded from the unit was 2 Megohms. The "tin can" construction (shown in Fig. 2) of soldering every joint except the gasketed seal for the terminal slab of unfilled phenyl formaldehyde proved both simple and effective. As will be seen in Fig. 4, the leads to each of the five windings were brought out individually so that all possible combinations of polarities and connections could be tried. The windings were each designed for a continuous rating of 200 Watts on the assumption of a good flow of water over the magnet, and reached this capacity on 20 Volts. After actually running the magnet to full capacity for some four hours, the terminal plate was removed and the windings inspected. No over-heating appeared to have occurred, nor was any smell of over-heating detected.
- (14) Clearly shown in Fig. 5 are the diamond-shaped pole shoes which were made fully removable and held by the single counter-sunk screw shown, so that other types could be tried if necessary. The original design shown proved so successful that no others were tried.
- (15) A mild-steel feed hopper mounted by means of the H-bracket (16) to the cradle frame (3). Figs. 3 and 4 show clearly the series of holes provided in this frame so that the position of the hopper could be varied and the best point found at which to feed the sand on to the belt. The upper bolt (17) passed through a slotted hole in the H-bracket (16) so that it could be pivoted about the lower bolt sufficiently to provide adjustment of belt tension just a little greater than that which would be effected by removing one section from the Whittle Vee Belt.
- (18) Two bearings for the feed-roller shaft (19), which also acted as the countershaft for the reduction drive to the main driving-belt pulley. This ratio was so arranged that the surface speed of the belt was a little greater than the peripheral speed of the feed roller (20). All shafts were of stainless steel.
- (20) Fig. 5 shows the feed roller: though many types of surface grooving were tried, a plain cylinder proved best. The roller first used was of brass, but, as this wore fairly rapidly, it was reduced in diameter and an eighth-inch ($\frac{1}{8}$ in.) thick rubber sleeves was fitted to it; it then performed and resisted wear very well. The cause of the wear was traced to the presence of a few larger particles in the sand which, unable to pass through the feed gate, rolled about behind it, thus wearing the roller away. When the surface of the roller is resilient, such a particle, on becoming wedged, is carried through, and does not unduly wear the surface. With the grooved type of roller, it was found that little feed occurred until the gate (21) was opened at least the diameter of the sand grains, and beyond that point a very great increase in feed was obtained for a small increase in gap, so much so, that the wear occurring during a run (one hopper full) almost

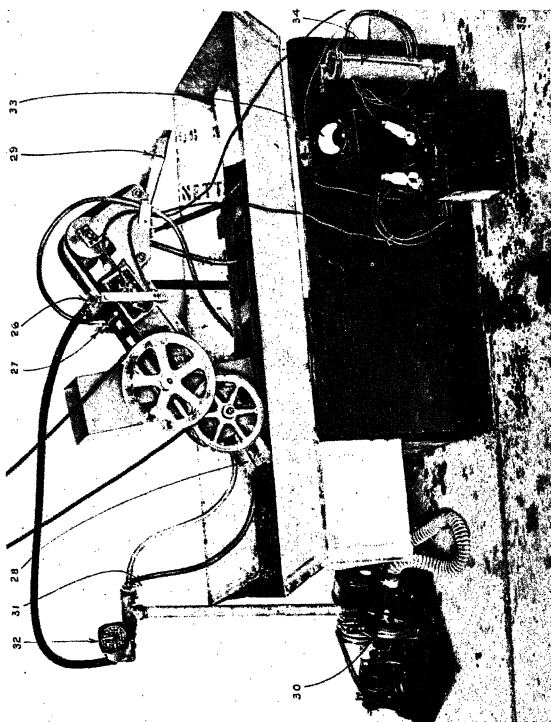


FIG. 4.—Close-up view of separator, showing constructional details.

doubled the feed rate towards the end. With the cylindrical roller, however, the gate gap was not very critical, a much larger gap being required, and little wear if any seemed to occur at the gate; the machine would then remain in adjustment for several days.

- (21) The feed gate adjusted for normal feeding is shown in Fig. 5. The maximum width of the gap for clearing is half an inch.
- (22) A locking screw for the feed gate was placed inside the hopper, because the splash guard (23) made it inaccessible for manipulation.
- (23) Just showing in Fig. 4 is a splash guard that was found to be

necessary after the machine had been built. Previous mention has been made of the difficulty of feeding damp sand. It was early found that the occasional splashing of water on to the exposed feed rolled (see Fig. 1) was sufficient to prevent the sand from feeding through the gate. This splash plate was then fitted and effectively cured the trouble.

- (24) A Whittle half-inch Vee belt, which was used so that the hopper position could be readily adjustable. The machine was driven by a $\frac{1}{4}$ h.p. motor with a capacitor starting; a $\frac{1}{2}$ h.p. would have been better, perhaps, as there was a full load for the $\frac{1}{4}$ h.p. motor; an ordinary split-phase starting motor could not develop sufficient torque to start the machine. The large amount of power absorbed by this fairly slow-moving machine (100 r.p.m.) is no doubt due mainly to the large frictional load of the belt against the magnet. The surface speed of the belt was varied by means of the relative sizes of the motor and counter-shaft pulleys and secondary drive ratio between the belt-driving shaft and the feed-roller shaft being kept constant at 4:15.

- (25) A slotted brass tube that delivered a high-velocity fishtail jet of water against the under surface of the up-grade belt and so sluiced the concentrate from it.

(NOTE.—From here onwards refer to Fig. 3.)

- (26) Another fishtail water jet which provided the main stream of water that carried away the gangue. This jet required careful design. It was found best that the water should issue in a symmetrical streamlined sheet, at a velocity about equal to its equilibrium velocity down the belt and with a slight velocity component from either edge towards the centre.

- (27) A brass tube providing two auxiliary fishtail side jets which served to divert towards the centre any gangue which, travelling against the sides of the belt due to stagnant water conditions and extra friction there, would not otherwise have been rejected.

- (28) and (29) Two brass chutes which collected the discharged sands and water and delivered them into suitable containers. Gallon paint tins were available and proved very convenient, as the annular groove around the top provided a very effective trap for any fines tending to escape. The discharge water carrying the sands, after losing its velocity and dropping the sands at the bottom of the tins, escaped at slow speed over the levelled rims of the tins and down to the sump.

- (30) A centrifugal recirculating pumping unit which made the machine largely independent of water supply and ensured constant water conditions wherever operated.

- (31) Brass throttling cocks by means of which the desired "head" could be applied to the fishtail jets (25), (26), and (27).

- (32) An old aircraft airspeed indicator which, suitably connected, served as an excellent low-pressure water gauge in the supply to jets (26) and (27).

- (33) A voltmeter across the electro-magnet coils.

- (34) A rheostat for adjusting voltage applied to the electro-magnet between battery tapings.

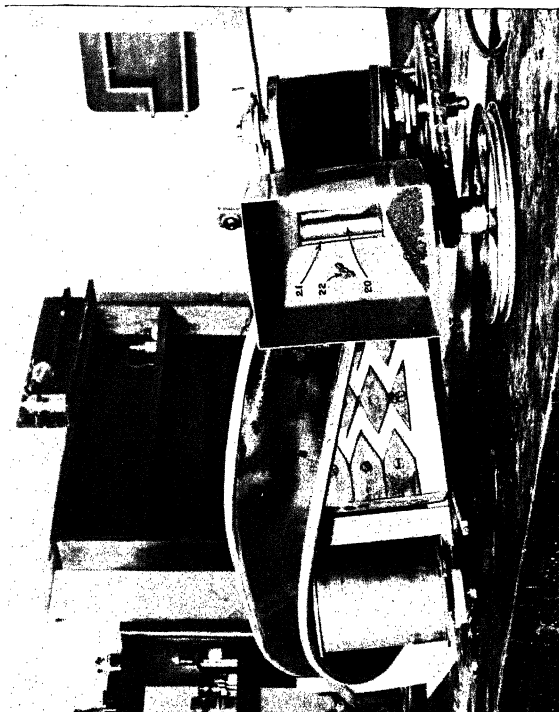


FIG. 5.—Close-up view of the top face of the electro-magnet, showing the pole shoes; showing also the details of the feed gate and roller.

(35) Twelve-volt accumulator with a dry-plate rectifier floating across it.

The original lubricant, water, was quite satisfactory for testing the performance of the machine. When the machine proved successful and was to be employed to obtain six tons of concentrate, other means of lubrication were considered.

Water-pump grease proved to be a suitable lubricant and was injected to the centre of the bearings by means of standard grease nipples and drilled shafts.

It served the double purpose of keeping stray sand out of the bearings,

as its high viscosity allowed it to form a good seal, and also when any excess was injected, it flushed out any sand that did get in.

Though mostly running wet, the stainless steel in phenol formaldehyde bearings proved very satisfactory.

MODIFICATIONS TO ALLOW OF CONTINUOUS WET FEED WITH A VIEW TO GIVING CONTINUOUS PRODUCTION

When required to produce six tons of concentrate, it was found possible to devise a very simple wet feed. A Humphry spiral concentrator was employed to remove much low-density material from the particular beach sand, and the high-density fraction, consisting of magnetite, ilmenite, and garnets in roughly equal proportions, was fed directly to the separator as pulp.

Fig. 1 shows schematically the only feed arrangement found necessary—viz., a flat-bottomed galvanized iron chute inclined beyond a particular critical angle. This chute was so arranged that the sheet of pulp impinged on the separator belt in the middle of the high-density flux region between the lowest and next series of pole shoes. The magnetic sand grains tended to form a continuously falling magnetic curtain on to the belt, while a great proportion of the gangue was swept away by the downward drag of the main water stream before it reached the belt. This simple expedient greatly increased the capacity for production and made the operation continuous and automatic. A wet feed, however, is not suitable for sampling work where full recovery of the sand fed in is required; oven-dried samples are then best. The feed chute can just be distinguished leading from the spiral to the magnetic separator in Fig. 6.

OPERATION

To operate the machine, it was first well hosed down, keeping all water from the feed hopper, but making sure that the belt and pulleys were well wetted, as these relied on water for lubrication. The edge of the belt was lifted and the face of the magnet given a copious wash, to remove any slight accumulation of magnetic sand from between the pole pieces, which sand would tend to short their magnetic flux. The machine was very satisfactory in this respect, and would normally run a whole day without undue collection of magnetic sand between the pole pieces. The water pump was then started. The cocks on the jet lines were always left open and used only as throttling adjustments. Then, having been pulled round by hand to make sure there were no obstructions, the machine was started. The hopper was always left empty, as no means of stopping its discharge, other than the feed gate, was provided, and this, having been set, it was not convenient to use it as an on-off control. The magnet current was then switched on, the collecting tins levelled up, and the machine was ready for use. The hopper was designed to hold a gallon tin of sand (30 pounds). Normally, the machine was left running continuously, as this eliminated continual adjustments. The collecting tins could be readily changed while separating. If it was necessary to stop it, it was, as before mentioned, essential to shut off the water pump first, or else a blocked hopper would result. This did not apply if the hopper was empty.

OPERATION ANALYSIS

Five zones can be distinguished in the operation of the machine.

Gangue Discharge Zone

Beyond the influence of the lower end of the magnet to the lowest point of the belt:



FIG. 6.—General view of the separator set up at Gillespie's Beach, South Westland, and taking wet feed from a Humphry Spiral Concentrator.

Non-magnetic sand grains are swept down the belt by the water stream, and both fall under gravity from the lower end of the belt and are carried by the lower chute to discharge.

Feed and Major Separation Zone

From the point where the feed impinges, to the lower limit of the magnet's influence:

When the dry sand falls on to the belt, the magnetic grains are immediately pulled under the surface, but the non-magnetic, being slower to sink, are mostly swept away and so a major separation occurs here. The magnetic particles, with considerable gangue occluded in them, pass up into the next zone. A little magnetic sand is similarly carried downward with the gangue, but, as it has to travel across some three inches of magnetic path and through a very strong field gradient at the edge of the magnet, it is practically all arrested, and can be seen moving upward under the down-travelling gangue.

More Critical Separation Zone

The magnetic path from lower to top gap between the rows of pole shoes:

Here the occluded gangue is separated as the sand is rolled about, due to the zigzag magnetic path, and the gangue exposed to the scavenging water stream. A long path, slow belt speed, and high water velocity favour good separation. The selected speed and the estimated length of magnetic path seem quite adequate for the thickness of sand and water sheet allowed by the three-eighths of an inch high sides of the present belt without spillover.

In this zone there was a tendency for gangue at the edges of the belt to escape separation due to the extra friction of the side strips; this was found to be the major cause of a slight contamination of the concentrate by gangue, particularly chips of sea-shell. Two small jets of water (27) (Fig. 3) were directed into the corners between the belt and its side runners at the position shown, and served to force any material there away from the side and into the turbulence of the main separation stream; this immediately remedied the only evident functional defect of the machine.

Transfer Zone

From the middle of the last pole gap to the top of the belt path:

In this zone the concentrated, gangue-free, magnetic sand passes through the impinging water curtain and is carried clear of the magnet's influence, ready for removal in the succeeding zone. It was found best to make the main jet impinge on the middle of the last inter-pole gap and take advantage of the slightly greater pull on the magnetic sand towards the belt, to assist the concentrate through the water curtain. Once through the curtain, and while the sand is still held to the belt for a further three inches of magnetic path, the water drains from it; by the time it is passing from the magnet's influence through a fairly strong field gradient that has considerable retaining tendency, it is sufficiently dry for the normal friction due to gravity to carry it onwards.

Concentrate Removal Zone

The under down-grade slope of the boomerang path from jet (25) (Fig. 3) downwards:

Here a high-velocity water jet sluices the concentrate from the belt into the discharge chute. The situation is most favourable, as the sand has only to be wetted sufficiently to release the surface tension forces of the little water that holds it to the belt, when it falls under gravity away from the belt.

TRIAL ADJUSTMENTS

The inclination of the belt, the belt speed, and position of the hopper were first roughly adjusted. It was soon evident that there was little danger of losing the ironsand from the field of the magnet; the hopper was placed low down, so that there would be a longer path for the magnetic fraction to traverse, and so increase the efficiency of dross removal. The best position for the feed to contact the belt was found to be in the middle of the lowest pole shoe gap. The belt speed was varied over wide limits, 110 feet per minute being chosen as about the optimum. If the inclination was small, the belt carried a large volume of water at a lower speed before spilling over, while at steep inclination a smaller volume at a higher speed seemed to give the same separating effect. The slope was set roughly at 30° and a more systematic study of separating made.

The next characteristic of the separator to be explored was the magnetic field. At the design stage the field required was largely a matter of conjecture, so all available space was utilized for windings, and the electro-magnet designed to the thermal limit of the space and materials. It was felt that the poles should be of alternate polarity, but a trial with them all of the same polarity was made in case some false assumption had been made. However, such a scheme showed no promise, and little effect was obtained on the sand, even at full field strength; this was expected because of the high reluctance of the magnetic circuit and the small field gradients. Then trials were made with the windings connected in parallel and to give alternate polarity. The D.C. supply was from two 12-Volt storage batteries that were continuously charged from a dry-plate rectifier. Starting at 20 Volts, the voltage was reduced by stages to two Volts per winding, samples being run through at each stage. At 20 Volts practically all material that could be called magnetic was retained, and successively lesser amounts were retained as the voltage was reduced. At 10 Volts the separation was into about equal parts: the non-magnetic fraction contained no ironsand, but the magnetic fraction contained a great proportion of the hybrid particles mentioned before and dross. Visual examination under the microscope was the method of assessing the quality of the magnetic fraction, and a powerful Alnico magnet was employed to detect traces of ironsand in the non-magnetic fraction. As the voltage was reduced, successively less of the dross was retained, and the quality of the magnetic fraction improved, while but little ironsand was found in the non-magnetic fraction, until at the last 2-Volt stage a small amount was detected. Attention was then concentrated on the angle of inclination of the belt and the size and position of the top jet (26) (Fig. 3). The conclusions reached about this jet were that it should be of such a size that the required volume of water left it with a velocity about equal to the terminal velocity of the stream, as determined by the inclination and friction conditions of its course. A slot of $3/32$ in. width gave the best performance. Later, two auxiliary jets (27) (Fig. 3) were added as explained before; these jet openings were $3/64$ in. by $\frac{1}{2}$ in. in length. A slight adjustment of the slope to 35° seemed to improve performance, but slope was not a very critical factor. Still a little ironsand was being lost, but the magnetic fraction was a very promising sample. The rate of feed was reduced to about half, and loss of ironsand immediately fell to negligible proportions, with no change noticeable in the magnetic

fraction. Under these conditions the throughput was about 280 pounds per hour.

When endeavouring to obtain the highest possible grade of concentrate, the main problem is to eliminate all possible composite particles, i.e., those consisting of both magnetic mineral and gangue locked together. By reducing the velocity of the water from the main jet (26) (Fig. 3) by increasing the port width until on hitting the belt it had attained only its equilibrium velocity down the belt, it was found that a magnetic field just strong enough to hold the sand in the separating zone would also allow it to pass through the water curtain. By suitably adjusting the strength of the field, it was then possible to eliminate practically all the composite particles and give, with the Patea ironsands employed, a concentrate some 3 per cent. richer in iron than any before obtained, even after carefully sorting a small sample with a hand magnet.

It is evident that to obtain reproducible results when working to such critical limits, the strength of field and rate of flow of the water from jets (26) and (27) had to be constant. The accumulator source of current and the electrically driven centrifugal pump gave such conditions.

OPERATING ADJUSTMENTS

Operation Conditions for Best Possible Separation

- A 9.5-inch head of water applied to jet (26) (Plate 1);
- 1.25 Volts applied to the electro-magnet in parallel connection;
- A belt speed of approximately 90 feet per minute;
- An angle of inclination of 35°.

Extrapolating from the curve of field strength versus applied voltage as measured between 2 and 20 Volts, the field at the edge of the pole shoes would be about 105 Oersteds for 1.25 Volts.

The operating conditions in the machine described, for the best possible separation, were—

Conditions for Obtaining a Good-grade Concentrate at a High Recovery

- A 14-inch head of water applied to jet (26);
- 35° angle of belt inclination;
- 110 feet per minute belt speed;
- 3 Volts applied in magnet coils on parallel connection, which gave a field strength of about 240 Oersteds.

Under these conditions, numerous hybrid particles were found in the concentrate.

OPERATION IN THE FIELD

After satisfactory use in the laboratory, assessing the proportion of ironsand in samples of black sand from many New Zealand deposits, the separator was employed in the field to separate six tons of magnetite sands for steel manufacturing trials recently conducted in New Zealand.

Fig. 6 shows the general set-up at the beach and how the magnetic separator was arranged in series with a Humphry Spiral. The Spiral rejected the low-density minerals and fed the heavy minerals to the magnetic separator, which extracted a 99 per cent. magnetite mineral from the 30 per cent. magnetic feed.

It will be seen that the only feed distributor necessary was a flat-

sectioned chute that gave even distribution of the sand and water pulp. It was found that this chute had a well-defined critical slope at less than which the pulp would not distribute itself evenly. The chute was set at slope just beyond the critical, this ensuring free flow of feed with a minimum of velocity on impact with the separator belt. By making the chute of galvanized steel and landing the feed in the middle of the first inter-pole gap, considerable help to separation was obtained in the curtain that formed between the chute and the separator.

ACKNOWLEDGEMENT

The writer expresses appreciation to Dr. E. R. Cooper, Director of the Dominion Physical Laboratory, Department of Scientific and Industrial Research, for permission to publish this paper.

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SETTLEMENT ANALYSIS OF A GASHOLDER AT SOUTH DUNEDIN

By K. S. BIRRELL, Soil Bureau, Department of Scientific and Industrial Research, Wellington.

Summary

An attempt has been made to interpret observations of the settlement of a gas-holder with a cellular raft-type of foundation in the light of modern soil mechanics theories. Soil tests have indicated that the major part of the settlement of the structure for the 18 years during which readings have been taken is due to a condition of plastic flow in a bed of soft estuarine deposit 49 feet thick underlying the foundation. A minor part of the settlement is due to consolidation of this soil layer. The plastic movement seems to be still taking place. The soft estuarine deposit possesses an unusually high liquidity index for a recent deposit. The moisture content and shear strength appear fairly uniform in the lower 35 feet of the soft clay layer, but adjacent to the holder there appears to be an increased shear strength to about 20 feet below ground-level as a result of the consolidation which has taken place. With the present stage of knowledge of soil mechanics, it is not possible to predict the ultimate settlement of the holder, but readings should be continued. Large raft foundations, even when lightly loaded, are not likely to prevent excessive settlement of structures in the South Dunedin area, and piles carried into the firmer underlying strata seem to be the only satisfactory method of preventing excessive settlement.

INTRODUCTION

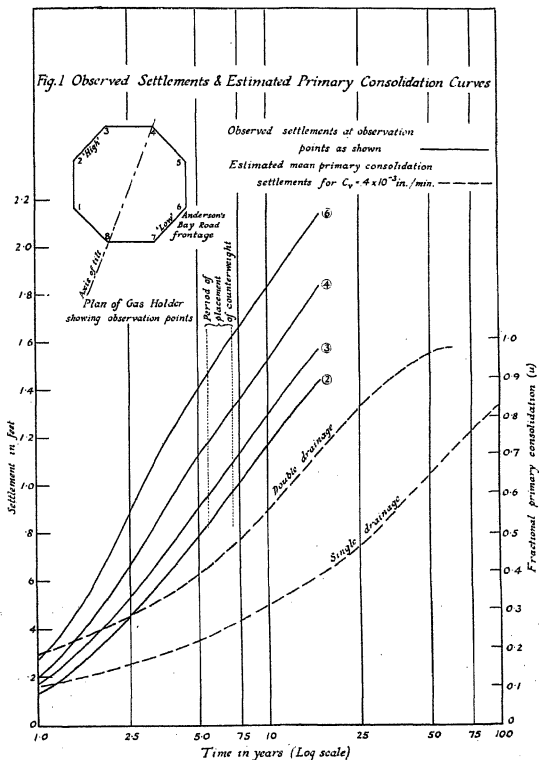
The area around the head of Otago Harbour, part of which has been reclaimed during recent years, is well known by local engineers to offer difficult foundation conditions. In particular, the residential and light industrial area of South Dunedin, which may be considered as bounded by Anderson's Bay Road, the Main Trunk railway embankment, Forbury Road, and the sand dunes of Ocean Beach, has a bad reputation in this respect. As satisfactory pile foundations in this area are costly and have been little used, the settlement of structures is evident to the eye in and around Cargill and King Edward Roads. The post office building situated in King Edward Road, erected in 1915, has been so badly damaged within recent years by differential settlement that it required demolition (see Fig. 6).

Successive engineers to the City Corporation gasworks, adjacent to the Anderson's Bay Road, have been aware of the settlement of their structures, and during the construction of a new gasholder with a cellular raft-type of foundation a programme of precise levels was commenced. These were first taken in March, 1931, by Mr. E. Fletcher Roberts, consulting engineer, of Dunedin, and have been repeated annually. The gasholder was designed in England, on the basis of information regarding the underlying soils which was available at the time and of the satisfactory behaviour of a vertical retort house in the works. Although settlements were anticipated, soil mechanics methods of predicting them were not then widely known. However, in view of the possibility of uneven settlement, a column-guided holder was decided upon. The level readings were taken as a precautionary measure, in particular to find if it would be safe to operate the holder with the full design height of water seal.

Mr. Roberts suggested in 1946 that it would be worth while investigating the soil conditions at the site, and the records of settlements to date have since been made available to the writer. The opportunity for

soil investigation was welcomed by the Soil Bureau to provide a useful check on methods being used for the examination of sites for large buildings in other parts of New Zealand.

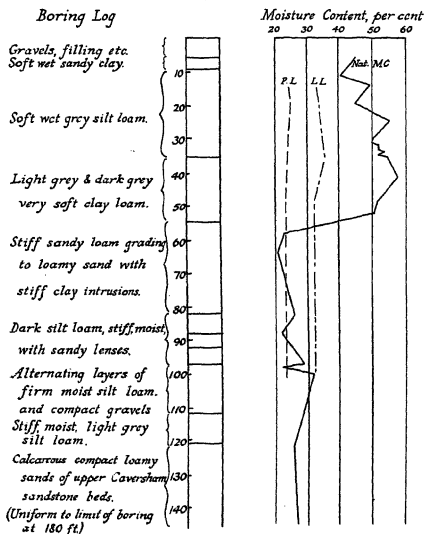
Although the settlement of the holder to date is of the order of 20 inches (see Fig. 2), no serious damage has resulted, and it has been possible



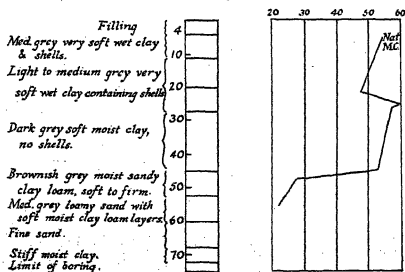
to adjust the mains connections as required. (The full-design height of water seal of $18\frac{1}{2}$ feet has been maintained in the holder since it was put in service.) A tilting of the holder which became evident soon after it had been put in service has been controlled by a counterweight of scrap-iron applied to the base on the high side. This was applied in increments

Fig 2-Bore Logs, Soil Moisture Liquid and Plastic Limits - South Dunedin

(a) Meter House, Gasworks



(b) Former Post Office, King Edward Road



between November, 1936, and March, 1938, to a total of $33\frac{1}{2}$ tons. The almost parallel trend of the settlement curves recorded for points around the circumference of the structure during the last ten years shows that this remedy has been reasonably effective (see Fig. 1). Water has, however, found its way into the base, and an automatic pumping system has been installed to maintain the water-level at a depth of 4 inches in the outer chambers. The holder was built with the base of the foundation 6 feet below ground-level, and ground water-level is normally about $3\frac{1}{2}$ feet below the surface. It is possible that this seepage is due to cracking of the base slab. Whether or not there is water in the inner chambers of the foundation also is not known.

DESCRIPTION OF SOIL STRATA

The sequence of strata from the main bore at the gasworks site may be described in general as follows. More detailed textural descriptions and a plot of moisture and soil-index test results are shown in Fig. 2 (a) :

- (1) Six feet of man-made filling, consisting of quarry waste, etc.;
- (2) Forty-nine feet of soft dark-grey soil varying from silt loam to clay loam texture, with occasional large shells;

The dark colour is due to finely divided iron sulphide, and, on exposure to the air, the colour rapidly changes to yellowish-brown. This layer will subsequently be referred to as soft silt loam.

- (3) Sixty-six feet of firm sandy loam, but including also some layers of fine sand and silt loam;

The change in consistency from the soft silt loam to the firm sandy loam is quite abrupt. No shells were found in the latter layer, but there were some wood fragments.

- (4) Fifty-nine feet of weakly cemented loamy sands, belonging to the Caversham Sandstone Formation.

The change was suggested by the coarsening in texture from the compact silt loams at the bottom of the overlying stratum, and became more evident by the high carbonate content of the samples (46 per cent. as CaCO_3). Proof of the identity of this material with the Caversham Sandstone was supplied by a micro-faunal examination carried out by Dr. H. J. Findlay, of the New Zealand Geological Survey. This stratum was fairly uniform in physical appearance, and, as the Caversham Sandstone is known to be several hundreds of feet thick in this district, boring was stopped at 180 feet.

A sequence similar to the above to a depth of 72 feet was revealed by the boring made at the South Dunedin Post Office site in King Edward Road. This profile is shown in detail in Fig. 2 (b).

The sequence of strata found in the course of borings at a site for oil storage tanks near Logan's Point was also somewhat similar to the above. These borings were made under Soil Bureau supervision on behalf of the British Petroleum Company of New Zealand, with whose permission data relating to this site are quoted. At Logan's Point, the stratum corresponding to soft silt loam at the gasworks is mostly of clay texture, and is less than 30 feet thick. Underlying this are fine sands. The Caversham Sandstone beds are absent, but igneous rock was found at depths varying between 29 feet and 63 feet.

EXPLORATION AND SAMPLING PROCEDURE

According to information received from Mr. H. Horrocks, gas engineer, of Dunedin, a shaft 50 feet deep was excavated some years ago in the gasworks property, and hand boring was continued to 30 feet below the bottom of this shaft. The material traversed was all classified as "harbour silt." When the timbering was removed, the bottom 20 feet of the shaft collapsed. It was apparent from this result that the thickness of soft sediments was considerable, and in order to make a complete investigation it was decided to hire percussion well-boring equipment. A bore lined with six-inch casing was made 100 feet distant from the holder, the hole being advanced by removing the material with a bailing pump operating inside the casing. This position was as close to the holder as it was possible to operate without interference to traffic and service mains. The soil was classified by examination of large pieces brought up by the pump, and three large samples were taken in the soft clay loam layer at depths of 30 feet, 36 feet, and 41 feet respectively. A Sprague and Henwood "Maine" type split barrel soil sampler fitted with detachable head and cutting shoe was used, taking samples $4\frac{1}{2}$ inches in diameter and 16 inches in length, the core samples being retained in thin liners of tinsplate which were capped and sealed for transport to the laboratory.

The area ratio of this sampling tool was 27 per cent., which, although slightly greater than that of equipment used in England, is low enough to class the tool as suitable for obtaining satisfactory samples^{1, 2}. With one blow of the drop weight this sampler could be driven in the soft silt loam almost the full distance required. Subsequent examination of the samples in the laboratory disclosed no obvious disturbance due to the sampling operation.

Large samples were not taken in the firm sandy loam immediately underlying the soft silt loam, since previous tests on soils of similar consistency and texture from Christchurch indicated negligible settlements for loadings comparable with that of the gasholder.

Subsequently, two exploratory bores were made within 10 feet of the holder, using a one-inch Porter-type piston soil sampler which could extract seven consecutive soil cores six inches in length at each insertion. One bore on the "high" side of the holder with respect to the tilt was taken to a depth of 70 feet, and the other on the "low" side to 30 feet.

The samples taken by this method were used for moisture content and field textural classification purposes only. No consistent differences in soil conditions which would account for the tilt were found between these bores. Post-hole borings were also made at these locations to obtain samples for shear tests by the unconfined compression method of Cooling and Golder³. It was not possible by this procedure to obtain samples at depths exceeding 20 feet, owing to collapse of the sides of the borehole. Soil moistures and soil textures at these bores were similar to those obtained at the six-inch bore (see Table I).

SOIL TEST RESULTS

Index Values

In addition to the natural moisture, liquid limit, and plastic limit results shown plotted on Fig. 1, data from other samples taken in the district are shown in Table I.

It will be seen that the range of textures covered by these samples is fairly wide. The important soft silt loam stratum at the gasworks is, however, fairly uniform; from 6 feet to 20 feet below ground-level, the texture is silt loam, and from 20 feet to 55 feet it is clay loam.

It is of interest that the natural moisture content at all sites is higher than the liquid limit, and in most cases the liquidity index is considerably above unity, which, as the result of considerable evidence from the papers of overseas investigators, is the accepted order of this quantity for recent sediments. The only conspicuous example in the literature of a sediment of natural moisture content considerably in excess of the liquid limit is the lime mud from the Bahamas, known as "drewite," described by R. Terzaghi³, which consists of acicular crystals of aragonite. The soft silt loam from South Dunedin contains much micaceous material in the fine sand fraction which may contribute to this effect, but the mineralogy of the clay and silt fractions, which is also under investigation, may help to explain this anomaly.

The natural moisture contents of samples from the firm sandy loam stratum underlying the soft silt loam are considerably lower than the corresponding liquid limit values. The most likely explanation is that this is a much older cycle of deposition, where some degree of desiccation has been produced by an uplift of the sediments.

TABLE I. MINERALOGICAL ANALYSES AND INDEX TESTS

Location	Depth (ft.)	Mechanical Analysis				Moisture Content %	Liquid Limit %	Plastic Limit %	Liquidity Index
		Clay %	Silt %	Fine Sand %	Coarse Sand %				
Caledonian Grounds	9	9	32	59	nil	60	32	23	4.1
Gasworks, 6 inch bore	13	12.9	26.6	55.5	0.1	49.2	33	25	3.0
	19	14.6	40.8	40.0	0.1	45.0	34	24.5	2.2
	24	25.4	37.4	29.9	2.8	55.6	38	24	2.3
	36	23.6	39.3	33.1	nil	54	35	24	2.5
	48	20.3	41.2	28.0	0.5	51.2	37	23	2.1
	88	19.2	20.3	60.5	3.1	21.5	24	19	0.4
	100	24	23	52.5	0.5	32.3	37	24	0.6
Oil Tank Site, Logan's Point	8	42	46	12	nil	86.5	57	44	3.3
	15	15	34	48	2.0	77.0	41	27	2.6
Post Office, King Edward Road	45	-	-	-	-	54	51	28	1.1

NOTES: 1. The mechanical analyses results are expressed according to the International scale.

2. Liquidity index = $\frac{\text{Moisture content} - \text{plastic limit}}{\text{Liquid limit} - \text{plastic limit}}$

Shear Tests

These were made only in the upper soft silt loam stratum. The unconfined compression method was used except that, for the sample from the Caledonian Ground, which contains the highest proportion of sand, a triaxial compression test was made, under conditions such that no water content change was possible, and gave an angle of shearing resistance of zero. The unconfined compression method was therefore reliable in theory for obtaining the shear strength of these samples. Samples were taken direct from the boreholes except that those from the six-inch bore were extracted in the laboratory from the $4\frac{1}{2}$ -inch-diameter cores taken with the sampling tool mentioned earlier. Table II gives the results of shear tests by this method.

It will be seen that the strength values of the samples from the gasholder fall into two groups. The samples adjacent to the holder to a depth of 19 feet appear stronger than those from the six-inch bore. This may be due to the consolidation of the upper layers by the holder,

TABLE II. SHEAR STRENGTH VALUES - UNCONFINED COMPRESSION METHOD

Location of Sample	Depth (ft)	Observed ultimate strength lb / sq. ft	% Strain for ultimate strength	Strength at 10 % strain lb / sq. ft	Strength at 20 % strain lb / sq. ft	% Moisture content
Caledonian Grounds	.9	330	20	300		60
Gasworks 6 inch bore	30	240	30	110	230	53
" "	30	285	30	180	230	53
" "	41	340	30	200	310	58
" "	41	310	30	180	275	53
Gasholder (low side)	9	750	12	740		42
" "	12	490	20	475		47
" "	16	450	20	440		48
Gasholder (high side)	10	510	16	480		42
" "	15	360	20	290		43
" "	19	380	14	365		53
Oil tank site		270 *	.	.	.	.

* Mean of 5 values ranging from 245 lb to 290 lb per sq. ft for samples from 6½ ft to 10 ft, with strain values for ultimate strength between 10 and 20 %.

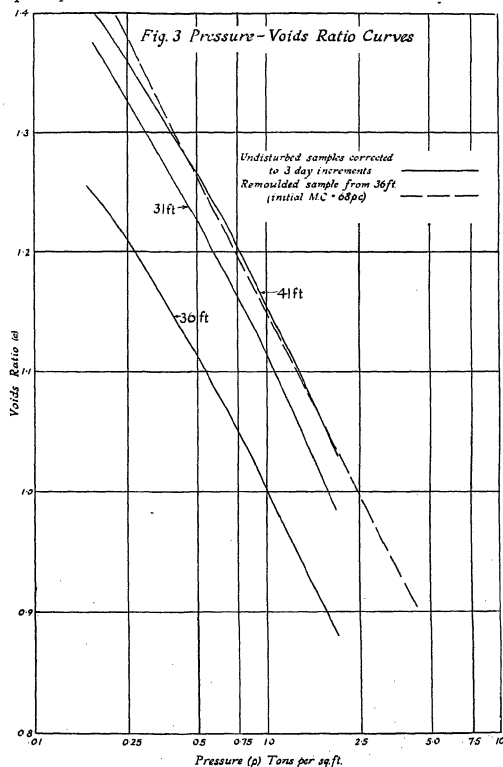
although, in the absence of corresponding samples from the six-inch bore, which is farther removed from large structures, this cannot be definitely decided. In this connection, however, the lower strength values given by the samples from the Caledonian Ground and the oil tank site where there are no structures in the vicinity may be significant.

The samples extracted from the large cores taken at the meter house when tested by the unconfined compression method gave, however, a rather unsatisfactory type of failure as compared with those from the other locations. Considerable bulging of the sample occurred with an absence of definite shear planes, and the maximum stress occurred only when the strain reached about 30 per cent. This may point to some disturbance of the samples, although this was not obvious on inspection. It is the usual practice, however, to carry out shear tests on smaller cores obtained from 4½-inch diameter samples from bore holes, and Skempton² has recently used this method for testing in the laboratory a fairly sensitive clay from the estuary of the Forth. The degree of sensitivity of the soft silt loam is not yet known, but it is intended to examine the strength of this soil stratum by means of the rotating vane procedures described by Carlson³ and more recently by Skempton², when it should be possible to evaluate the effect of sample disturbance on shear strength values, and to discover if the unconfined compression method is reliable for this soil type.

Consolidation Tests

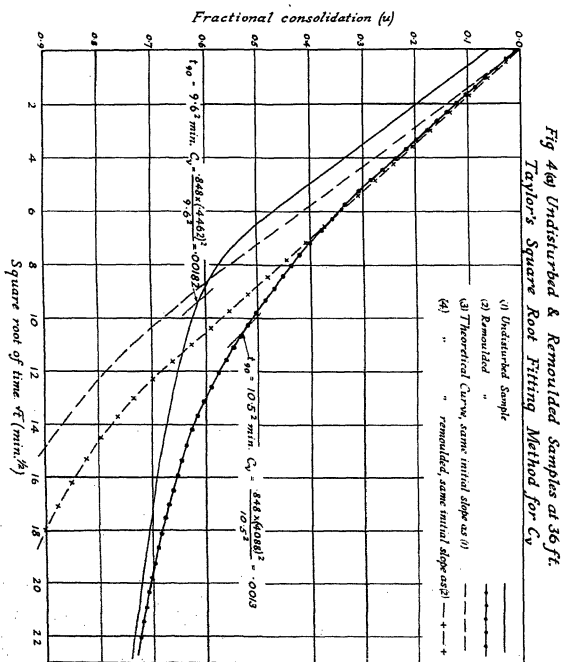
Three consolidation tests were carried out on cores 2½ inches in diameter, and 1 inch in thickness, cut from each of the large samples

from the bore at the meter house, and obtained as described in the previous section on "exploration and sampling procedure." The oedometer apparatus was of conventional design, the loading increments proceeding from 0.2 to 3.0 tons per square foot and in some cases to four tons per square foot. Most of these loads were left on only for the



conventional 24-hour period, since, owing to shortage of equipment, extension of the loading time would have held up other testing projects in hand. In two instances, however, the loads were left on for three days, and, in two other cases, for two days. It was found that appreciable additional settlement did occur after the end of the 24-hour period, and it seemed preferable to compute the total settlement due to consoli-

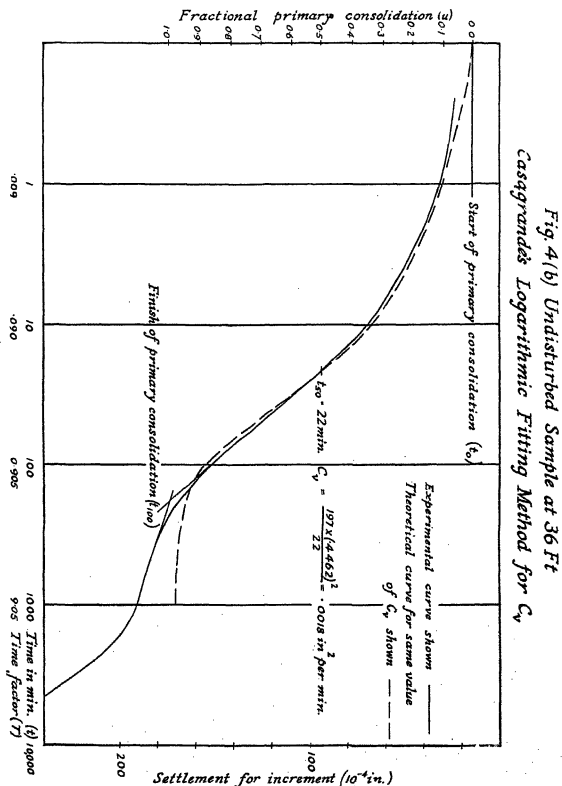
dation on the basis of a three-day period for all increments. Although insufficient information was available from tests on the natural samples to enable this to be done satisfactorily, tests subsequently carried out on a completely remoulded sample showed that for a load increment of 0.5 ton about 80 per cent. of final settlement would occur in 24 hours, and for a load increment of four tons about 95 per cent. in the same



time, and that the proportion of settlement in 24 hours for intermediate loads could be roughly calculated. The results obtained from the isolated increments of longer duration on the natural samples confirmed that the interpolation of calculated results gave a fairly good approximation of the final settlement, and consequently all 24-hour increments were transformed to three-day increments.

The results of the tests are shown in Fig. 3, in which the void ratios of the soil, as calculated from the observed thickness change after the

conclusion of each loading increment, are plotted against the applied pressure on a logarithmic scale in the usual manner. The application of these curves to the calculation of the ultimate settlement of the gas-holder will be described later.



The pressure-voids ratio curves for these samples show some abnormal features. As the soil appears to be somewhat sensitive to remoulding, a more pronounced initial curvature, by comparison with samples of sensitive clays given in the literature, would be expected. The curves when corrected to three-day increments as described above are, however, almost straight. The original curves for one-day increments show

some curvature, but it is only of a comparatively minor order, and there is no possibility of identifying the Casagrande preconsolidation load.

The remoulded specimen was made up at a moisture content of 68 per cent.—that is, higher than that of the undisturbed sample, and its initial voids ratio is likewise considerably higher than that of the natural soil. It would be expected that the compression curve would show an initially steep curvature, and it would then gradually flatten out and lie beneath the line for the natural sample, as can be deduced from the curves given by Skempton for the Gosport clay⁸. However, a straight line is obtained for the relationship between voids ratio and pressure over the range 0.25 to 4.0 tons per square foot. It is not possible with the present information to offer an explanation of these apparent irregularities, and clarification must await further work.

In order to compute the time rate of settlement of the gasholder due to the consolidation effect, the approximately constant "coefficient of consolidation" was calculated from the results of the consolidation tests. Where the initial and secondary compression stages are unimportant with respect to the primary compression effect, which alone conforms with the Terzaghi theory, a simple method of calculation of the coefficient as used by Cooling and Skempton for London clay¹ would be applicable. This method of calculation depends on obtaining a linear relation between U , the fractional compression of the sample at any instant for values of U up to 0.52 and $\sqrt{t}$ where t is the time measured from the moment of application of the load increment. Although the initial settlement stage is quite small for the gasholder samples, the secondary effect is very marked, and obviously sets in at a very early stage. Fig. 4 (a) shows the curve for the 36-foot sample for the increment 0.4 to 0.6 ton per square foot compared with the theoretical curve having the same slope over the linear portion as the experimental curve. This increment was applied for three days, but other increments of about the same order applied for only one day gave still more divergence from the theoretical curve. It is of interest to note that the remoulded sample in Fig. 4 (a) also shows a marked though lesser divergence from the theoretical curve than does the corresponding "undisturbed" sample.

A remoulded London clay sample investigated by Cooling and Skempton¹ shows very little divergence from the theoretical curve.

The presence of the secondary compression effect can also be seen in Fig. 4 (b), where U is plotted against $\log t$ for the same undisturbed sample as in Fig. 4 (a), and for the same loading increment. For comparison, the curve for this relationship based on the Terzaghi theory is also shown in Fig. 4 (b). The increase in slope of the experimental curve beyond the point where $t = 1000$ minutes is an unusual result. This effect was also obtained from the remoulded sample with loading increments up to 0.6 ton per square foot.

In order to try to eliminate the effect of secondary compression from laboratory time-settlement curves, so that the settlement of a structure due to primary compression can be plotted, three methods of curve fitting are available. These are—

(1) Taylor's method;

(2) Casagrande's method;

(3) A new method depending on the almost linear relationship between $\log 1-U$ and t for values of U between 0.6 and 0.8 proposed by Naylor and Doran¹⁰.

The procedures and relative merits of these methods are discussed by Naylor and Doran in their paper.

It was found in the present investigation that there was considerable irregularity in the values for the coefficient of consolidation, as found in the three samples tested, even by one particular method, and it was difficult to decide on a reasonable value to take for the coefficient in order to compute the rate of settlement of the holder due to the primary consolidation effect.

None of these methods is apparently suitable for isolating the primary consolidation effect when secondary compression is, as in the present investigation, a large part of the settlement process. It was found that the three methods gave values of different orders for the same sample and increment. Taylor's method gave the highest values. Casagrande's was next in order, while Naylor and Doran's tended if anything to give results lower than those given by the simple $U:\sqrt{t}$ relationship. Casagrande's method was applicable in only a few instances, owing to the difficulty in finding a definite inflexion point to the curve to indicate the end of the primary consolidation stage. With the available results, the most reasonable value for the coefficient in the primary consolidation stage for the three samples would be 4×10^{-3} in.² per minute, this being an average value given by Taylor's method for the increments up to one ton per square foot. The selection of Taylor's method value is, nevertheless, open to the valid criticism made by Naylor and Doran that it can be misleading if secondary compression begins before $U = 0.9$, but this difficulty would probably arise, although to a lesser extent, with their own method for these samples, since they have assumed no secondary compression before $U = 0.8$. Their method requires here a tedious double correction in order to obtain the required straight line in the region where $U = 0.6$ to 0.8 , and it apparently alters the value of C_v but little from the value given by the $U:\sqrt{t}$ relation, which is of the order 10^{-3} in.² per minute. In spite of the obvious shortcomings of Taylor's method, the selected value for C_v should give a reasonable upper limit to the settlement rate of the gasholder. More satisfactory values would have been obtained with all methods if each increment had been of three-day duration, but because careful planning of the times of taking readings is required, particularly when using Casagrande's method of curve adjustment, a better procedure might be to use thinner samples of, say, half an inch in thickness. This would, however, have required alterations to the apparatus which were not convenient to make at the time, and might also have caused difficulties due to the presence of small shells in the samples. The range of values given by increments of three-day duration are shown in Table III for the undisturbed and remoulded cores from 36 feet depth. However, this sample gave for all increments values of C_v of a lower order than did the other two samples, so that the figures in this table do not indicate an average result. The finer textured sample from the oil-tank site gave more consistent results by the various methods of adjustment, the secondary compression effect being less apparent.

TABLE III.—COEFFICIENT OF CONSOLIDATION GIVEN BY PROPOSED METHODS

Sample	Increment of Loading tons/sq. ft.	Coefficient in in. ² per min. from Adjustment method $U:\sqrt{t}$ relation		
		(1)	(2)	(3)
36 ft. Undisturbed gasworks	0.4 to 0.6	.00075	.0018	.0018
36 ft. Remoulded gasworks	0.4 to 0.65	.00044	.0015	.00077
	0.65 to 1.2	.0012	.0029	.0015

SETTLEMENT OF GASHOLDER DUE TO CONSOLIDATION

The unit loading of the structure at foundation level is 0.36 ton per square foot, allowing for six feet of soil excavated for the foundation and assuming ground water-level to be at 3½ feet below the surface. Taking a Boussinesq distribution of pressure in the soft silt loam, the pressure at the bottom of this stratum will be 0.2 ton per square foot. Assuming further that the soft silt loam is in equilibrium with the natural overburden pressure at all depths, the procedure of Palmer and Barber¹¹ for estimating the ultimate settlement of the holder due to consolidation gives the following values for the three samples tested:—

31-foot sample	19.5 inches
36-foot sample	20.3 inches
41-foot sample	18.5 inches

The mean result is 19.4 inches.

Physically, it is doubtful from the moisture, liquidity index, and shear strength results if the deeper layers of the soft silt loam have reached equilibrium under the natural overburden. Although this difficulty has engaged the attention of soil mechanics investigators, it has not yet been satisfactorily solved. If one takes the rather extreme view that the original load on the soft silt loam before the structure was built nowhere exceeds that due to the topmost layer of filling, etc. (amounting to about 0.3 ton per square foot), the ultimate settlement figure would be increased to approximately 25 inches. It is the usual practice, however, to assume, when making settlement estimates, that compressible layers of soil are normally consolidated in nature¹².

It has been found that for many clay soils the compression index C_c is related to the liquid limit approximately by the relation $C_c = .009$ (L.L. — 10 per cent.), where C_c is equal to the tangent of the slope of the linear portion of the pressure-voids ratio curve (see Fig. 2). The experimental results are compared with those calculated from the above equation in Table IV for some Dunedin soils.

TABLE IV.—VALUES OF COMPRESSION INDEX FROM EXPERIMENTAL CURVES AND LIQUID LIMIT RELATIONSHIP

Sample	Liquid Limit	C_c from p-e curve	C_c from liquid curve/limit
Gasworks, 36 ft.	36	0.38	0.23
Oil tanks, 8 ft.	57	0.52	0.42
Oil tanks, 15 ft.	41	0.49	0.28

Since the settlement of a structure is proportional to the compression index for the soil, use of the liquid limit relationship would not give a reliable estimate of the magnitude of settlement to be expected with these soils. Terzaghi states that the correlation of compression index and liquid limit relationship does not hold with extra-sensitive clays, but the Dunedin soils do not give pressure-voids ratio curves typical of such clays, at least within the range of pressures covered in these tests.

The settlement curves for the gasholder based on consolidation theory are shown in Fig. 1 for conditions of single and double drainage of the soft silt loam layer, the value for C_v being taken as 4×10^{-2} in.²/minute for the reasons given earlier in this section. It is considered that drainage is likely to take place mainly through the rubble filling under the concrete base of the holder. The underlying firm sandy loam stratum will not be sufficiently permeable to allow free drainage, so that the actual conditions would approximate to that of a clay layer draining from the upper face only. Tschebotareff¹³ has discussed the drainage of clay layers sandwiched between other soil layers of comparable permeabilities, but he considers it unlikely that a usable relation for computing settlement rates can be arrived at for these conditions. It is probable, therefore, that the actual settlement of the gasholder will be slightly faster than represented by the single drainage curve in Fig. 1, but considerably less than for the double drainage curve. It is to be noted also that the double drainage condition predicts an average settlement for the first two years greater than the observed values.

SHEAR STRESSES UNDER STRUCTURE

If it be assumed that the gasholder acts in a similar manner to a uniformly loaded circular area resting upon a semi-infinite isotropic elastic medium, data published by Jurgenson¹⁴ show that there would be a zone of maximum shear stress of the order of 250 pounds per square foot equal to

$$\frac{\text{unit foundation load}}{\pi}$$

under the perimeter of the holder, and occurring in a zone roughly between five feet and 25 feet below the base of the foundation. Shear stresses of this order would occur under the centre of the holder only at depths greater than the bottom of the soft layer, where the calculated stress is about 230 pounds per square foot.

It is probable, however, that the stresses in the soft silt loam layer are actually higher than those computed for a semi-infinite elastic medium due to the change to a stronger layer at 55 feet depth. Jurgenson states that for the case of a rigid layer such as rock occurring at a depth equal to one-fourth the width of a long uniformly loaded strip, the principal shear stress will be increased by as much as 60 per cent. above the corresponding value for a semi-infinite elastic medium.

Since the basic mathematical data¹⁵ which Jurgenson has made use of in his calculations are not at present available in New Zealand, it is not possible to compute what percentage of additional shear stress would be produced at the base of the soft silt loam layer under the particular conditions at the gasholder site, assuming that the firm sandy loam behaves as a rigid boundary.

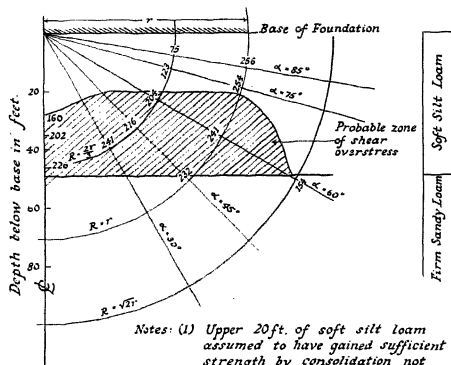
DISCUSSION

Since the main object of the investigation was to compare the observed settlements with the values predictable from soil tests, the main points of interest are that the mean settlement to date is about three times the most reasonable value which can be deduced from consolidation tests, and that the settlements for all corners of the holder are still proceeding at a rate considerably in excess of that given by consolidation theory.

This effect could conceivably be produced by a considerable overstress in shear of the soft silt loam layer, but since the weight of the structure

Fig. 5 Shear Stresses under Gasholder

Shear Stresses indicated by number at points shown (lb. per sq. ft.)
(r = radius of circle of equivalent area = 69 ft.)



Notes: (1) Upper 20 ft. of soft silt loam assumed to have gained sufficient strength by consolidation not to be overstressed.

(2) Data from Jurgenson (14) p.176.

has been approximately uniform it is surprising to find settlements due presumably to a plastic flow condition so much in evidence after 18 years, although the average annual settlement rate is now decreasing markedly, the amount for the year ending December, 1949, being one-fifth of an inch. When the estimated shear stresses given in the preceding section are compared with the shear strength values given in Table II the strengths at 10 per cent. strain (average about 160 pounds per square foot) give good evidence for a large zone of considerable shear overstress (maximum value about 50 per cent. even if no additional stress increase at the firm sandy loam boundary is assumed). The shear stresses under the structure are shown in Fig. 5 with the over-stressed zone hatched. If the assumption regarding increased stress in the neighbourhood of the firm sandy loam boundary is made, a condition of shear overstress will result with strength values corresponding to higher values of strain than 10 per cent. In this connection, it is to

be noted that the Swedish Geotechnical Institute¹⁶ uses the shear strength value at 10 per cent. strain as being the critical value for rupture of the soil, as found by analysis of circular arc failures.

The extent of the overstressed zone and the order of maximum over-stress shown in Fig. 5 is comparable with data given by Glossop¹⁷, but unfortunately he gives no description in his article of the behaviour of the structures. He suggests, however, that this condition will give rise

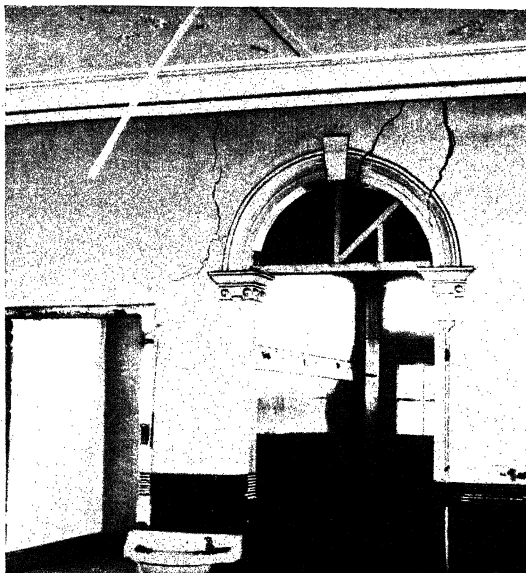


Fig. 6.—Damage due to settlement in former post office, King Edward Road (now demolished).

to lateral strain and the settlement will be greater than that predicted by consolidation theory, but that the magnitude of the additional settlement can be estimated only from actual cases where this condition of over-stress occurs. A satisfactory basis for design of the holder on present knowledge which would allow settlements to be predicted from consolidation tests would be that shear stresses in the soft layer nowhere exceed 100 pounds per square foot, i.e., allowing for 60 per cent. of additional stress at the base of the soft silt loam layer.

A better idea of the over-stress conditions under the holder may be obtained if further shear tests are carried out with the vane-type instrument referred to earlier, and if more exact methods become available

for computing shear stresses for the particular conditions revealed at the gasworks site.

The variations in rate of consolidation of these soils seemed greater than could be accounted for by variations in texture. It is possible that the type of sampler used in England for handling soft clays¹ may give better results than the split-barrel type used in this investigation.

It is apparent, however, that the soft silt loam soil from the gasworks site has rather unusual properties which render determinations of shear strength and consolidation data rather difficult to carry out so as to obtain results readily applicable to practical problems.

CONCLUSIONS

(1) The discrepancy between the observed settlement rate and that predicted by the theory of consolidation can on present evidence be accounted for only by postulating a long-term condition of plastic flow in the soft silt loam layer.

(2) The evidence that plastic flow is due to considerable shear over-stress requires to be investigated by further tests at the site and in the laboratory, although on present evidence it is likely that the maximum amount of shear overstress is at least 50 per cent.

(3) The ultimate settlement of the holder due only to the consolidation effect will be of the order of 20 inches, but the real settlement may be several times this value. It is not possible at present to predict the magnitude and course of the real settlement. The amount of consolidation which has taken place to date probably does not exceed 50 per cent. of the ultimate value.

(4) Settlement records should be continued, although it does not appear essential that they be taken annually.

(5) The magnitude of consolidation settlements for structures on the South Dunedin soils cannot safely be predicted from their liquid limit values.

(6) Large structures, even where the unit loading is quite light, should not in general be built in the South Dunedin area unless pile foundations are used. Large rafts with loads in excess of a quarter of a ton per square foot may overstress the soil. For smaller footings, the effect of slight shear overstress would not be so serious, but some settlement due to consolidation would result.

ACKNOWLEDGEMENTS

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NOTE ON CONTROL OF EARTHWORMS IN GREENKEEPING

By G. S. HARRIS, Grasslands Division, Department of Scientific and Industrial Research, Palmerston North.

Summary

Following on the results of overseas work¹, an investigation was made into the use of derris dust as a worm control under New Zealand conditions. From the viewpoint of convenience of application, effectiveness, economy, and relative non-toxicity to other animals, it appears to have decided advantages in comparison with other methods.

EXPERIMENTAL

An experiment was conducted using the commercial preparation of rotenone derris dust for the control of garden pests, and the results showed that the concentration of active agent "rotenone" (0.5 to 0.7 per cent.) was insufficient. By increasing the rotenone percentage, the optimum kill of worms was recorded at a content of 4.0 to 4.1 per cent. at $\frac{1}{2}$ oz. of preparation per square yard.

After using 4.0 to 4.1 per cent. of rotenone derris dust at $\frac{1}{2}$ oz. per square yard on four plots each one yard square, placed at random along base lines of a tennis court (where mowing was impossible because of worm casts), the following observations were made:—

- (1) Over a period of six days, 602 worms were killed.
- (2) Maximum kill occurred after 24 hours.
- (3) Toxic effects were apparent for a further six days.

Although derris dust was not as quick-acting as some other agents, it was found that all worms brought to the surface died within a short period. With some of the other treatments, the worms are brought to the surface quickly, but they recover, and, unless swept up immediately and destroyed, a certain number return to the soil. Rainfall after application enhances the effect of the treatments.

Derris dust was found to be equally as effective as other chemical worm controls, and in some cases gave a better result. The investigations described were solely for the purpose of obtaining comparative data, and further detailed work will be necessary before final recommendations can be made. However, the following points will be of interest to greenkeepers:—

- (1) Derris dust having a rotenone content of 4.0 to 4.1 per cent. definitely kills worms.
- (2) Importers and manufacturers can supply this product. The effective rate of application is $\frac{1}{2}$ oz. of derris dust per square yard washed in with one gallon of water.
- (3) If control measures are undertaken when the worms are active, and in mild, showery weather, the dust will be washed into the soil and the amount of water required to be added will be reduced. One-quarter of an inch of rainfall is equivalent to approximately one gallon of water per square yard.
- (4) There is every indication that much smaller quantities of derris dust (containing 4.0 to 4.1 per cent. rotenone) will be effective.
- (5) Derris dust is reported to be non-toxic to warm-blooded animals, but should not be allowed to contaminate ponds or streams, since it will affect fish. Toxic properties of the derris dust begin to deteriorate after twelve months storage.

Further investigational work on such aspects as duration of control, effect on worm capsules in the soil, and rate of application is being carried out.

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**QUARTZOSE COAL MEASURES OF WEST NELSON AND
NORTH WESTLAND**

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Summary

The stratigraphic relation between the quartzose coal measures and the overlying basal marine beds of west Nelson and north Westland is reviewed. Only exceptionally is there any evidence of other than a conformable sedimentary contact between them. The lowest marine beds are shown to become progressively younger northwards, and it is suggested that the top of the quartzose coal measures becomes younger in the same direction. This demands the abandonment of age correlations suggested by previous authors. The palaeogeographic implications are briefly discussed. Older rocks, including older coal measures, were first reduced to a peneplain. In some districts quartzose coal measure deposition began in small terrestrial geosynclines, but before marine beds were laid down in each part of the region, the rising base level during marine transgression caused deposition of similar terrestrial beds almost everywhere.

INTRODUCTION

At the base of the Tertiary sequence in west Nelson and north Westland, coal measures of which quartz is the dominant constituent, rest unconformably on older rocks and are overlain by marine beds. The Brunner beds of the Greymouth coalfield are typical of these coal measures, and have been described by Morgan (1911) and more recently by Gage (1949b). From the general similarity of coal measures in the Westport, Reefton, Murchison, Wangapeka, Heaphy, Takaka, and north Collingwood districts, correlation of these with the Brunner beds is tempting, the stratigraphic position below basal marine beds being a further similarity. In this paper the term "quartzose coal measures" is used for all these coal measures. Recent determinations of macro-fossils by Dr J. Marwick and micro-fossils by Dr H. J. Finlay show that these basal marine beds differ in age, ranging from Bortonian in the Greymouth Coalfield to Duntroonian in north Collingwood.*

* The Tertiary stages used are those proposed by Finlay and Marwick (1947).

PREVIOUS CORRELATIONS

The following correlations have previously been adopted:

Fox River. Wellman (1946a, p. 218) states: "There is no evidence against correlating . . . with Brunner beds the high-sulphur quartzose coal measures near the coast, which . . . grade up into marine beds of Kaiatan age."

Westport Coalfield. Morgan and Bartrum (1915, p. 73) state: "There is no difficulty in correlating the Brunner and Kaiata beds with the corresponding strata in the Greymouth district," and note (p. 71) "They [the Kaiata beds] correspond in character with the Kaiata mudstone near Greymouth, and in age with the same strata plus the Island sandstone."

Reefton Coalfield. Henderson (1917) placed the coal measures at Reefton in the Miocene, but later (1929) the same author states: "the coal-measure[s] in the neighbourhood of Reefton . . . undoubtedly also belong here" (i.e. with the Brunner beds of the Greymouth district).

Murchison District. Fyfe (1928) describes the quartzose coal measures of the Murchison district under the heading of "Brunner beds," although later (1930) he describes them as part of his Marnia Series, and gives no correlation.

Henderson (1929) discusses correlations of Late Cretaceous and Tertiary rocks, and divides the coal measures of west and central Nelson (and Greymouth) into two groups. Those at Fox River, Westport, Reefton and Marnia he correlates with the Brunner beds of Greymouth. Those at Charleston, Buller Gorge, Westhaven, Motupipi, Three Channel Flat, Fletcher Creek, Owen, and Wangapeka, he correlates with the Port Elizabeth beds (Whaingaroan) of Greymouth. Thus, although at all the localities he mentions that the coal measures have the same stratigraphic relation to overlying marine Tertiary beds, he recognized that they are not all of the same age. His correlations divide the coal measures essentially into bituminous and lower rank groups, and may well have been influenced by this factor. Gage and Wellman (1945) showed that widely differing ranks of coal may occur in coal measures of the same age in different places, and this conclusion is adopted in the present paper.

It is clear that Morgan and Bartrum in dealing with the Westport Coalfield, and Henderson in his correlation over the whole region, have used the term "Brunner Beds" with an age significance and not as a formation name.

In a departmental report on the Heaphy Coalfield, Wellman (1948) correlates the coal measures of the Heaphy Coalfield with those which underlie the Tertiary marine beds at Takaka and Collingwood (excluding the Pakawan Series of Collingwood). He infers that there is no break between the coal measures and marine beds, and using the assumption that a relatively uniform rate of subsidence controlled the rate of deposition, he considers the coal measures to be Arnold in age. The age of the marine beds immediately overlying the coal measures is given as Landon, without any stage determination.

Finlay and Marwick (1948, p. 17) mention the Brunner coal measures as possibly Cretaceous, and later (p. 30) it is stated that

"part or all of the coal-bearing Brunner group may be lower Eocene." There are no further references to the age of the quartzose coal measures in north-west Nelson and north Westland and it appears likely that the term "Brunner group" is used to include all the quartzose coal measures in that region, thus assigning a similar age to them all.

DESCRIPTION OF LOCALITIES

The following descriptions of the sequences are illustrative of the whole region, it being impracticable to describe every available section.

Greymouth Coalfield. Over much of the Greymouth Coalfield the Island Sandstone of Bortonian age follows the Brunner coal measures with apparent conformity. Near Blackball mine the lowest part of the Island Sandstone contains conglomerate bands, and on the Blackball railway, rare small coal lenses are interbedded with the marine sandstone. Similarly a half-inch coal layer is recorded in the Island Sandstone in Bore 253 (Dobson), 200 feet above the top of the Brunner beds.* Gage, whose detailed work on the Greymouth Coalfield will shortly be published as the New Zealand Geological Survey Bulletin 45, "The Greymouth Coalfield," has recently summarized some aspects of this work (1949a, 1949b). He states (1949b, p. 343): "the final re-sorting of the uppermost layers (of the Brunner beds) was done by waves and currents during the marine transgression that brought the coal-forming period to a close." From this it appears that he considers that the period of Brunner coal formation continued up to the time when the sea invaded the area, and consequently that the deposition of the Brunner beds was followed immediately by the deposition of the Island Sandstone.

In a paper, "Paparua-Brunner contact near Greymouth," now in the press, Wellman has described an erosion interval between Brunner coal measures and Island Sandstone, but has not attributed any considerable time significance to it.

The thickness of Brunner coal measures in the Greymouth Coalfield ranges from 50 to 400 feet.

Fox River Mouth. Near the mouth of Fox River, 28 miles north of Greymouth, about 100 feet of coal measures, consisting of quartz sandstone and conglomerate with sub-bituminous coal, are followed with apparent conformity by well-bedded soft carbonaceous sandstone and this by hard calcareous sandstone with Kaiatan fossils. In this area near the coast "quartzose coal measures . . . grade up into marine beds of Kaiatan age" (Wellman, 1946a, p. 218). In the same page the author correlates these quartzose coal measures with Brunner beds in the Fox River headwaters which "grade up into the marine Island sandstone (Bortonian)." This implies correlation of the Brunner beds in these two areas, despite the fact that they are followed by Bortonian in Fox River headwaters and Kaiatan at Fox River mouth.

* Morgan (1911, p. 59) records a workable coal seam in the Kaiata mudstone. During the remapping of the Greymouth Coalfield by Gage, it was shown that a fault had obscured the correct sequence and that the coal is within the Brunner coal measures.

Reefton Coalfield. The following sequence through the Kaiata—coal-measure contact was recently penetrated in Bore 103 in the Reefton Coalfield:—

Mudstone with glauconitic bands and scattered marine fossils	200+
Carbonaceous clay with traces of coal	8
Carbonaceous sandstone, grits, and sandstone	68
Carbonaceous shale	6
Mudstone	19
Sandstone	17
Mudstone	15
Carbonaceous mudstone with marine fossils	10
Shale and traces of coal	3

The mudstone at the top of the section closely resembles the Kaiata mudstone at Greymouth, and the fossils were given a Kaiatan age. The beds below this mudstone appear to be similar to the 400 ft of coal measures penetrated below them, the lower mudstone with marine fossils being exceptional. The sequence suggests that for some time after the first incoming of the sea into the area the supply of material was sufficient to build the sediments above sea level. The non-marine nature of the lower part of the coal measures is shown by the presence of fresh-water lamellibranchs 100 feet above the bottom of the coal measures.

Similarly in Bore 101, drilled a few months before Bore 103, marine fossils were recorded below sandstones and mudstones with coaly bands.

Henderson (1917, footnote to p. 86) notes that shell-fragments occur below coal seams at Waitahu River, only a short distance from the recent bore.

At Garvey Creek coalfield, five miles south-east of Reefton, a section through the coal-measure—marine-bed contact is excellently exposed on the road to the colliery. The transition from bedded coal measure sandstone with coal seams to poorly fossiliferous siltstone being so gradual that it is impossible to decide exactly where the one ends and the other begins.

The coal measures at Reefton are about 400 feet thick and at Garvey Creek coalfield about 800 feet.

Westport Coalfield. The following quotations from Morgan and Bartrum (1915) present good evidence for gradation between coal measures and marine beds in this area. In dealing with the Brunner beds they state (p. 77): "it should be noted that in places a coarse sandstone not far above the coal may possibly be marine." In describing the Kaiata beds, they state (p. 79): "The hard gritty sandstone seen in the lowest portions of St. Andrew and St. David streams may belong either to the lowest horizon of the Kaiata beds or to the upper part of the Brunner beds." Their conclusion is that "whilst the Brunner beds were being laid down the land gradually subsided, and at last marine conditions almost imperceptibly supervened" (p. 72).

The coal measures in the Westport Coalfield range from 20 to 500 feet in thickness.

Maruia. This area lies 14 miles south-west of Murchison and 16 miles north-east of Reefton. The following section from coal measures to marine beds is typical of those exposed in small creeks draining to Maruia River about one and a-half miles south-west of the junction of Coffee Creek and Maruia River.

	<i>Feet</i>
Massive gritty sandstone with minor carbonaceous mudstone ..	200+
Coal	0.2
Thick sandstone with thin coal and coaly mudstones ..	100
Carbonaceous mudstone with marine fossil band near top ..	100
Dirty coal	1
Quartz grit, sandstone and thin carbonaceous mudstone ..	20

This section is noteworthy in that thin coal occurs in sandstones above the lowest marine fossils, and in that the composition of the rocks both in the coal measures and in the marine beds is essentially very similar. There is no evidence of an unconformity in the section. The age given to the macro-fossils is Kaiatan. The thickness of the coal measures ranges from 50 to 200 feet in this district.

Owen River. The following section from coal measures to marine beds is exposed partly in a small creek and partly on ridges, within 30 chains east of the junction of Frying Pan Creek and the Left Branch of Owen River. This area lies 15 miles north-east of Murchison.

	<i>Feet</i>
Medium blue-grey siltstone with interbedded limestone bands	60
Glauconitic muddy fine sandstone with poor fossil fragments	25
Yellow-brown gritty sandstone with quartz pebbles ..	10
Gritty sandstone	20
Blue-grey medium and fine sandstone	150
Fine sandstone with interbedded carbonaceous mudstone and thin coal seams	10
Pebble conglomerate (quartz and greywacke)	5

There is no sign of unconformity in the section, and it is difficult to be certain where the marine-bed—coal-measure contact lies. The coal measures in this area are about 200 feet thick. The age of the mudstone at the top of the above section is Whaingaroan, but in this area lower samples did not yield identifiable faunae. Since, however, Runangan faunae were obtained from a poorly exposed section one mile and a half to the south-west, the lowest marine beds are likely to be at least as old as this.

A similar transition from coal measures to marine beds is exposed in numerous places along the Left Branch of Owen River from two to four and a half miles north-west of the section described above. The river flows across marble and argillite, which unconformably underlie the coal measures, then from coal measures to marine beds several times, and in no instance is there any evidence of unconformity between the coal measures and marine beds. From blue glauconitic mudstone immediately overlying coal measures, a Whaingaroan micro-fauna was obtained.

Kohaihai Bluff. The following section from the area near Kohaihai Bluff, on the coast 50 miles north-east of Westport, is reproduced from information kindly given by H. W. Wellman, who has recently examined the Tertiary sequence over a great part of Westland and Nelson.

	<i>Feet</i>
Calcareous quartz sandstone grading down from glauconitic quartz sandstone and grit	30
Quartz grit with poorly preserved fossils	5
Quartz grit grading down to pyritic quartz sandstone	45
Coal measures—shale, quartz sandstone, conglomerate and thin sub-bituminous coal seams	150

TABLE 1. LOWER TERTIARY SEQUENCES, WEST NELSON AND NORTH WESTLAND

[illegible]

There is no sign of unconformity between the marine beds and the coal measures, and the lithologies suggest a transition. The age of the lowest marine beds is probably Whaingaroan, which soon gives place to Duntroonian.

Wangapeka. This district, 30 miles west of Nelson, has been geologically mapped by Henderson, Grange, and Macpherson. No bulletin has been published, but short accounts of the geology are given in Annual Reports of the Geological Survey 1924-25. Henderson, Grange, and Macpherson (1925, p. 5) state: "The Tertiary rocks consist of arkositic grits and sandstones, grading up into sandy limestones," and make it clear that the lowest beds are coal measures by stating later that "thin seams of coal are present in the basal Tertiary rocks of the middle part of the Baton Valley." This area has recently been re-examined by Wellman, who, in a personal communication, states that there is no sign of a break between the coal measures and the overlying marine beds, the age of which is probably Whaingaroan. He also informs the writer that there is thin coal above the lowest marine fossils in Green Hills Creek, which joins Sherry River 30 chains upstream from the junction of the Sherry River and the Wangapeka River. The thickness of the coal measures is here about 70 feet, but increases rapidly westwards.

Takaka. This district lies 35 miles north-west of Nelson, and the Takaka Coalfield within it has been described by Wellman (1946b). In his description and cross-sections there is no suggestion of an unconformity between the coal measures and the overlying limestone, and he states (p. 192) that at Dry River "The limestone grades down into a 100 foot band of quartz sandstone, which overlies the first definite non-marine bed." Within the coalfield the coal measures range from several hundred to 1,600 feet in thickness.

Seven miles north-east of Takaka only a few feet of coal measures, with a seam of dirty coal, intervene between granite and the limestone; although the section is not well exposed, there is no reason to suspect an unconformity. Again, five miles north-west of Takaka, at Rangiheta Head, the dip of the coal measures is similar to that of the overlying limestone, although the actual contact is not exposed. Here the coal measures are at least 1,000 feet thick. The age of the limestone overlying the coal measures in the Takaka district is either Duntroonian or Waitakian.

Puapua. The following section is exposed at Abel Head, 12 miles north of Collingwood township:—

	<i>Feet</i>
Calcareous glauconitic sandstone with marine fossils grading down to	10+
Limonic medium and gritty sandstone	20
Conglomerate in sparse limonitic sandy matrix	2
White quartz grit with mudstone, coal lenses, and conglomerate bands	100+

The conglomerate with limonitic matrix clearly is part of the same sequence as the overlying limonitic sandstone which grades into true marine beds. This conglomerate contains pebbles similar to those in conglomerates of the typical coal measures below, the well-marked

difference being probably due to the re-sorting and removal of matrix consequent on marine transgression. Although current bedding makes it difficult to take exact dips on the coal measures, it is unlikely that there is any unconformity between the two sets of beds. Transition from coal measures to marine beds is well seen near the mouth of the Paturau River, 18 miles to the south-west, again no unconformity being apparent. The age of the lowest marine fossils has been given as Duntroonian. The thickness of the quartzose coal measures is probably several hundred feet.

PRESENT CORRELATION

From the descriptions given above certain generalizations can be made. Only exceptionally (at one locality in the Greymouth Coalfield) are the quartzose coal measures and the overlying marine beds other than conformable. Transitions or gradations are frequently found, with the result that it is difficult to be certain where the coal measures end and the marine beds begin. Coal, even though present only in thin bands, is not uncommonly found in the beds immediately above the lowest marine fossils.

In place of earlier correlations it is suggested that the top of the quartzose coal measures is immediately older than the lowest overlying marine bed, the age relations being given in Table I. These coal measures are regarded as being remnants of a once-continuous formation (except for monadnock areas) transgressing time-stratigraphic divisions.

The alternative, that the quartzose coal measures are all of the same age and that there is evidence of a break representing several Tertiary stages in some areas, is rejected. Had an interval existed, it must have been occupied in sub-aerial erosion and it is improbable that the coal measure-marine bed contact would show no signs of this suggested interval. An erosion break could be obscured by the re-working of the upper part of the remaining coal measures by wave action, when the transgression of the sea took place, but thin coal above the lowest marine beds suggests an interfingering of marine and terrestrial deposition. Furthermore, even a disconformable contact is unlikely if considerable times had elapsed between the deposition of the coal measures and the marine beds, judging by the "oscillation, foldings and local elevations that occurred throughout these epochs" (Finlay and Marwick, 1948, p. 22).

Studies recently begun on leaves and spores from New Zealand coal measures should lead to valuable information on the age relations of the quartzose coal measures of different areas.

AREAS WHERE QUARTZOSE COAL MEASURES ARE ABSENT

In a few areas of west Nelson and north Westland, thought to have been higher land standing above the general level of a peneplain, lower Tertiary marine beds rest directly on the Palaeozoic rocks or on granite, with no quartzose coal measures intervening. Two areas will be mentioned in detail together with their relation to neighbouring areas where quartzose coal measures are present.

Aorere Valley, Collingwood. In the Aorere Valley, seven miles south-west of Collingwood township, white crystalline limestone rests on an irregular surface of unweathered schist, angular fragments of which are embedded in the lowest part of the limestone. The crystalline limestone passes up into sandy limestone, from which Waitakian fossils have been collected. This area lies between the Westhaven district, ten miles to the north-west and the Takaka district, ten miles to the south-east, in both of which quartzose coal measures and above them Duntroonian marine beds underlie Waitakian limestone.

Mt Mantell, Murchison. Duntroonian marine beds rest on granite to the north-west and north-east of Mt Mantell, 12 miles south of Murchison. Eastwards and southwards there is no certain information as to the former presence or absence of quartzose coal measures, as upper Tertiary beds rest on the old rocks. Four miles to the west, however, in the Coffee Creek area, quartzose coal measures and marine Kaiatan to Whaingaroan are followed by Duntroonian marine beds, it being noteworthy that these thin eastwards towards the Mt. Mantell area.

ROCKS ON WHICH QUARTZOSE COAL MEASURES REST

The quartzose coal measures rest not only on Palaeozoic sedimentary and metamorphic rocks and granite intrusions, but also on Mesozoic terrestrial beds.

In a recent paper, "Paparoa-Brunner contact near Greymouth," now in the press, Wellman has shown that Paparoa beds (probably Cretaceous) have been deeply leached below unconformably-overlying quartzose coal measures. In a second paper (in press), "Ohika Beds and the Post-Hokonui Orogeny," he describes similar leaching of Ohika beds (doubtfully Jurassic) and draws attention to other areas in which quartzose coal measures rest unconformably on Mesozoic sediments in west Nelson and north Westland. These areas are: Reefton, where quartzose coal measures rest on Hawks Crag Breccia (probably lower Cretaceous) and possibly Paparoa beds; Fox River and Murchison, where they rest on Hawks Crag Breccia; and Collingwood, where they rest on the Pakawan coal measures. He notes that an erosion surface cuts across the Pakawan Series, which corresponds to the Paparoa beds of Greymouth, and that the quartzose coal measures rest on this surface. This surface is that figured by Cotton (1922, pp. 144, 145).*

* It is clear from this evidence that peneplanation took place later than the deposition of some post-Palaeozoic beds still preserved in the region. Under these circumstances the term "undermass" used by Cotton (1922) applies to all the pre-Tertiary rocks in north-west Nelson and north Westland, not only to the Palaeozoic sedimentary and metamorphic rocks and the granite intrusives, and that the term "covering strata" cannot strictly be applied to the Paparoa beds, Pakawan Series, Hawks Crag Breccia, and Ohika Beds. The retention by Wellman, in "Ohika Beds and the Post-Hokonui Orogeny" (in press), of the use of "undermass" and "covering strata" as stratigraphic terms differentiating between the Palaeozoics and associated granite intrusives (no lower Mesozoic rocks have been recognized in west Nelson and north Westland; the Triassics of east Nelson are the nearest, and probably these were also overlain by quartzose coal measures) and all younger rocks, may, however, be convenient enough to find acceptance.

Elsewhere the quartzose coal measures rest on Palaeozoic rocks and the major igneous intrusions into them, transgressing all boundaries between the different formations. Furthermore, they transgress the junctions between these formations and those Mesozoic rocks mentioned above as being overlain by quartzose coal measures. A very frequent feature of the contact is the leaching of the old land surface below the coal measures, almost certainly attributable (Wellman, "Paparua-Brunner contact near Greymouth," in press) to a widespread period of erosion and peneplanation.

CONDITIONS OF DEPOSITION OF QUARTZOSE COAL MEASURES

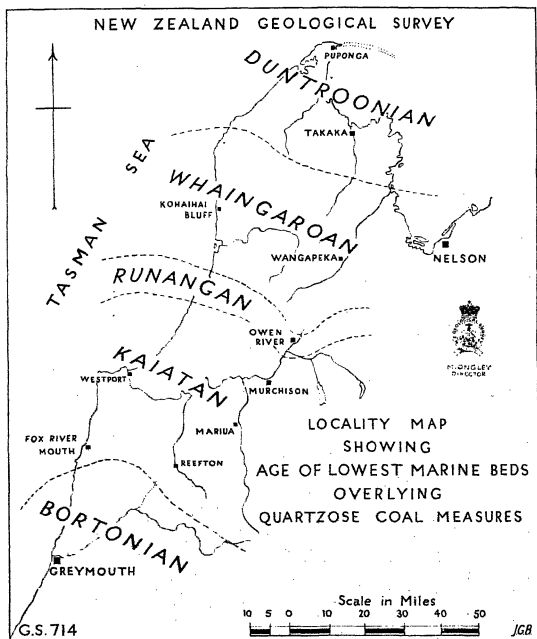
Gage (1949b, p. 343), in discussing the conditions of formation of the Brunner coals of the Greymouth Coalfield, gives the following account: "The highly specialised Brunner sediments were re-sorted many times during a long period with a minimum of transportation or addition of fresh material . . . The supply of sediment to the basin was insufficient to compensate even for the continued very slow subsidence, so that, although most of the Greymouth coalfield was probably a swampy plain, the neighbourhood of the axis of submergence was for a long time the site of a permanent body of water, in which accumulated the matter composing the thick and extensive Brunner Seam. The soil on land would inevitably have been deeply leached."

Morgan and Bartrum (1916, p. 72) consider that "there is strong evidence that at some period prior to the deposition of the bituminous coal measures the Buller-Mokihinui Subdivision was part of a great peneplain." They suggest that "The Brunner beds were deposited on a moderately level surface by a stream or streams that drained an area where granite and allied rocks predominated over sedimentaries. They are believed . . . to be in great measure deltaic deposits formed in a shallow lake or lakes."

Henderson (1917, p. 86), in discussing the coal measures of the Reefton district, states "that these beds were deposited on a gently undulating surface, which was probably a base-levelled land-surface", and considers that the coal measures are largely beach deposits.

It is thought by the present writer that there were essentially two different sets of conditions giving rise to the quartzose coal measures at the base of the Tertiary sequence. The first is the accumulation of coal measures in geosynclinal areas such as the Greymouth, Buller, and Takaka coalfields. The second is the accumulation of coal measures as deposits on a peneplain as a result of a rise of base level during marine transgression. This would result in relatively thin coal measures.

The Tertiary and, as shown by Gage (1949a), Cretaceous periods were marked in west Nelson and north Westland by the accumulation of sediments in small geosynclines. Subsidence in all these did not commence at the same time, and where it began before the widespread general sinking on which it was superimposed, major lateral variations in coal measure thickness were caused. In those areas where the geosynclinal phase had not already begun, a rising base level while the sea was transgressing caused deposition inland. This must



clearly also have affected those areas that had already been accumulating sediments as a result of geosynclinal subsidence, so that there will be no clear boundary between the sediments due to the two different sets of conditions. The minor variations of thickness of the quartzose coal measures reflect the relief of the peneplain on which they were deposited, and in some areas monadnocks of old land stood up, not being buried until after the sea had reached those areas. The sea is thought to have transgressed from the south over the peneplain, which was backed in the north by an area providing abundant sediment. Thus there was enough material to build up sediments above sea level in areas that had been submerged beforehand, permitting the formation of coal above the lowest marine beds.

During the period when terrestrial sediments were accumulating solely in geosynclinal areas, with the sea lying far to the south, these areas may well have formed more or less isolated basins, with con-

ditions similar to those postulated by Gage for the Greymouth Coal-field. That there was an area able to supply abundant sediment is shown by the great thicknesses accumulated in Arnold times immediately following the deposition of the quartzose coal measures. It is reasonable to expect that when the sea transgressed, widespread coverage by sediments, previously prevented under terrestrial conditions, would become possible.

The age of the base of the coal measures in each district can be estimated only from consideration of their thickness in relation to the conditions of subsidence postulated for the district prior to marine transgression. This requires the application of all stratigraphic data for the whole region and is outside the scope of this paper. Thin coal measures, however, followed by thick marine beds for each lower Tertiary stage, as in the Murchison district, are likely to represent less than one stage, whereas thick coal measures deposited in geosynclinal areas followed by relatively thin marine beds for each stage, as in the Takaka district, may well represent several stages.

Quartzose coal measures underlie marine beds over much of New Zealand and the lowest marine beds are of widely different ages. In the middle Waipara River in north Canterbury, for instance, they underlie Piripapan marine beds with no apparent break, and it is considered that here also the top of coal measures will prove to be immediately older than the lowest marine beds.

The Otaihangā Quartzite near Paraparaumu recently described by Macpherson (1948) as resting on "deeply weathered basement" which "seems to have been planed", contains "small lignitic shale fragments . . . in the upper part", and appears to be typical of the quartzose coal measures. It is overlain by Whaingaroan Māuapoko Greensand, Macpherson stating that "Angular discordance was not seen at the contact, but as the latter is nowhere well exposed, there may possibly be an unconformity between the quartzite and the overlying greensand." Suggested correlations are with the "chimaen" boulders and quartz grits of Central Otago, the grits and quartz conglomerates of the Brunner Beds, and the quartzose conglomerates and grit of Parapara, Aorere Valley, and Quartz Range (Collingwood-Takaka districts). This section in the southern part of North Island appears to record the same sequence of events as in west Nelson and north Westland.

The transition from coal measures resting on Mesozoic rocks to marine Whaingaroa Beds (Whaingaroan) in the Huntly-Kawhia Sub-division has been described by Henderson and Grange (1926), who state (p. 43) that "the coal seams and associated beds occur beneath the prominent limestone beds of the Tertiary sequence, and are the terrestrial, littoral, deltaic, and estuarine deposits of a sinking land. They did not all accumulate under the same conditions or at precisely the same time, but are the record at each locality of the transition from sub-aerial to sub-aqueous conditions."

It is most likely that the circumstances of accumulation of all New Zealand coal measures above peneplaned older rocks and below a marine sequence are due to the same cycle of events, peneplanation

preceding marine transgression, and that the extension of this suggestion to the whole of New Zealand will provide the full history of these happenings.

Forty years ago the conditions of deposition of coal measures in New Zealand were discussed by various authors in several papers. Two papers by Henderson (1910a and 1910b) discuss the coal measures and the Tertiary history of west Nelson. A paper by Marshall, Speight, and Cotton (1910) is concerned with the Cretaceous and Tertiary rocks of New Zealand. In all these papers the assumption is made that all the coal measures belong to one formation at the base of a series of marginal deposits overlapping on to an old land. Although it has since been shown that there are several coal measure formations with varying stratigraphic relations to marine beds, and that the deposition of younger rocks of New Zealand has largely been controlled by a series of small geosynclines, the conception of coal measures as basal terrestrial beds of a dominantly marine sequence is still tenable with respect to the quartzose coal measures.

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PRESERVATIVE TREATMENT OF RIMU AND MATAI SAPWOOD BY PRESSURE IMPREGNATION

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Summary

The results of pressure treatments of rimu and matai sapwood with aqueous solutions are given.

Gross absorption percentages obtained with the same combinations of initial air and solution pressures were found to be similar for both species.

Absorption of cold solutions, particularly into rimu, was very slow, but absorption rate increased rapidly with increase in solution temperature.

High negative correlation coefficients were found between net absorption and timber density.

Net absorption decreased with rise in initial air pressure, but increased with rise in temperature.

INTRODUCTION

AN investigation of preservative treatment of sap rimu (*Dacrydium cupressinum* Sol.) and sap matai (*Podocarpus spicatus* R. Br.) by pressure impregnation with aqueous solutions has been made. The equipment and methods used were described previously (Harrow 1947a, 1947b, 1948).

In both species, heartwood is resistant to solution penetration. As it is not possible to estimate the weight and volume of any included impervious heartwood, the absorption of sapwood portions of scantlings containing heartwood cannot be measured accurately; hence, it was necessary to select scantlings free of heartwood. With matai, this was difficult and some scantlings used in treatments did contain a little heartwood.

EXPERIMENTAL

Gross Absorption

Following three different initial air pressures, the gross absorption percentages produced by different solution pressures were determined by the method of Harrow (1947b). Results given in Table I show good agreement between species and with the gross absorption percentages reported for *Pinus radiata* (Harrow 1948). However, unlike pine, where a gross absorption of 75 to 80 per cent. resulted in complete penetration, scantlings of rimu and matai frequently had an unpenetrated core, even when gross absorption exceeded 90 per cent. One scantling of rimu 2 in x 2 in subjected to an initial vacuum of 20 in Hg. followed by solution pressure increasing in increments up to 400 pounds per square inch for a total period of 53 hours was found on examination to have a distinct untreated core although the gross absorption was 96 per cent.

TABLE I. GROSS ABSORPTION PERCENTAGES PRODUCED IN RIMU AND MATAI BY DIFFERENT COMBINATIONS OF INITIAL AIR AND SOLUTION PRESSURE
(Means of three runs)

Solution Pressure. lb per sq. in.	20in Hg.	0	20	40	60	80	100	150	200	250	300	350	400
Initial Air Pressure RIMU													
20in Hg.	11.8	37.4	70.0	81.6	91.1	92.0	94.0	94.6	95.3	95.5	96.3	96.3	96.3
Atmospheric pressure		11.4	44.1	67.3	76.3	81.0	84.1	87.2	89.1	90.1	91.0	91.5	91.9
20lb per sq. in			11.7	35.8	55.1	65.4	70.1	79.2	87.0	88.8	90.7	91.7	92.1
MATAI													
20in Hg.	13.9	57.4	81.0	84.2	85.6	86.5	91.0	95.5	96.4	96.5	96.6	96.6	96.6
Atmospheric pressure		14.1	61.5	72.8	77.7	82.3	84.7	87.3	90.1	90.9	92.7	92.7	93.0
20lb per sq. in			12.1	44.6	63.0	68.7	76.7	83.3	89.2	90.3	91.5	92.3	92.3

Note: First values for treatments correspond to percentage of void occupied by initial moisture content.

TABLE II. TIMES (MINUTES) TO INJECT 95 PER CENT OF TOTAL ABSORPTION INTO 2IN x 2IN MATAI AND RIMU SUBJECTED TO 0 TO 200 LB PER SQ. IN. PRESSURE TREATMENTS AT DIFFERENT TEMPERATURES—FIVE INDIVIDUAL SCANTLINGS PER TEMPERATURE.

Solution temperatures	RIMU					MATAI				
	Air	37°C.	65°C.	93°C.	Air	37°C.	65°C.	93°C.	Air	65°C.
Time in minutes	280	110	30	12	70	130	5			
	275	75	40	35	15	105	3			
	375	160	30	15	5	10	3			
	280	110	120	6	35	3	5			
	300	210	45	5	15	15	15			

Speed of Absorption

The rate at which absorption occurred with different pressures was measured during treatments in the investigation of net absorption.

In Table II is shown the times in minutes required to secure 95 per cent. of the total absorption into 2in x 2in scantlings of matai and of rimu subjected to a pressure treatment of 0 to 200 pounds per square inch at different temperatures.

Although absorption rate was most variable, results indicate that in general matai absorbs solution more rapidly than does rimu. Absorption rate of both species increased rapidly with rise in temperature.

These data show the importance of maintaining treating pressures until absorption into a charge ceases, in order to ensure that all timber in the charge is fully penetrated.

Net Absorption

Forty-three scantlings of rimu and 37 of matai 2in x 2in at least 8 feet long were impregnated individually with 2 per cent. boric acid solution by application of different combinations of initial air and solution pressures, and different temperatures. A further series of matai scantlings was treated with 2 per cent. tanalith solution. The gross absorption of each scantling was measured. After treatment, scantlings were held in a closed tank over water and weighed daily until constant weight indicated that kickback was completed. This required up to three days.

For each scantling the increase in weight above pre-treatment weight was recorded as net absorption, and was expressed both as a percentage of calculated oven-dry weight of scantlings and as pounds of solution per cubic foot of wood. Kickback (gross absorption—net absorption) was expressed as a ratio of gross absorption. The density (oven-dry weight, wet volume) of each scantling was calculated, oven-dry weight of a scantling being determined from the percentage moisture of two samples. The mean density of rimu was 0.44 ± 0.07 and of matai 0.50 ± 0.09 .

When air dry, treated scantlings were sampled for chemical analysis both in cross section for analytical loading and in 1/10th cores for core loading, as described (Harrow 1948) for *P. radiata*. The distribution ratio, $\frac{\text{core loading}}{\text{analytical loading}}$ was calculated for each scantling. The results of treatments are shown in Tables III, IV and V.

DISCUSSION

Data presented in Table III show that for rimu, net absorption and analytical loading were significantly reduced by increasing the initial air pressure to 20 pounds per square inch. Conversely, kickback ratio was significantly increased with rise in initial air pressure. Rise in temperature significantly increased net absorption. As indicated in the table, much of the variation in net absorption within treatments was caused by density differences. Statistical analysis of the results showed significant correlation coefficients of -0.88 between density and net

TABLE III. NET ABSORPTION OF SOLUTION, ANALYTICAL LOADING AND DISTRIBUTION OF SALT IN 2IN x 2IN KIMU IMPREGNATED WITH 2% BORIC ACID AT PRESSURES AND TEMPERATURES SHOWN (43 Treatments)

Pressure, lb per sq. in. Temperature °C.	0-80 Air	0-200 Air	0-200 38	0-200 65	0-200 93	20-200 38	20-200 65	20-200 93	Least difference for significance (5%)
Mean Net Absorption % adjusted for wood density	80.1	71.4	81.3	89.7	103.6	44.6	59.9	64.8	14.4
Mean Net Absorption % adjusted for wood density	78.1	77.3	78.3	87.4	104.6	50.5	53.0	66.2	7.1
Mean Net Absorption lb/cu. ft.	21.6	20.1	21.9	24.2	28.3	12.7	15.5	18.0	2.4
Mean Net Absorption lb/cu. ft. adjusted for wood density	21.3	20.8	21.5	23.9	28.4	13.5	14.7	18.2	1.9
Mean density	0.43	0.46	0.43	0.43	0.44	0.46	0.42	0.45	0.07
Mean kielcheck ratio	0.29	0.39	0.37	0.30	0.17	0.61	0.56	0.37	0.06
Mean Analytical loading oven-dry wood w/w	1.57	1.50	1.36	1.86	1.80	0.90	1.17	1.37	0.24
Mean Distribution ratio	0.36	0.49	0.59	0.60	0.63	0.49	0.64	0.63	0.26

TABLE IV. NET ABSORPTION OF SOLUTION, ANALYTICAL LOADING AND DISTRIBUTION OF SALT IN 2IN x 2IN MAYAI IMPREGNATED WITH 2% BORIC ACID AT PRESSURES AND TEMPERATURES SHOWN (37 Treatments)

Pressure, lb per sq. in. Temperature °C.	0-80 Air	0-150 Air	0-200 Air	0-200 38	0-200 65	10-150 Air	Least difference for significance (5%)
Mean Net Absorption % adjusted for density	58.6	68.3	60.2	53.4	58.9	42.2	14.4
Mean Net Absorption % adjusted for density	56.8	63.6	61.9	58.4	62.4	44.5	9.3
Mean Net Absorption lb/cu. ft.	18.1	19.8	21.0	17.3	18.8	13.5	2.2
Mean Net Absorption lb/cu. ft. adjusted for density	17.9	19.2	20.5	17.9	19.2	13.7	1.9
Mean density	0.39	0.48	0.48	0.58	0.52	0.51	0.06
Mean kielcheck ratio	0.38	0.38	0.35	0.44	0.41	0.53	0.06
Mean Analytical loading oven-dry wood w/w	1.18	1.18	1.38	1.02	1.16	0.95	0.13
Mean Distribution ratio	0.26	0.26	0.44	0.27	0.28	0.31	0.27

TABLE V. MEAN ANALYTICAL LOADING AND DISTRIBUTION OF SALT IN MATAI 2IN X 2IN IMPREGNATED WITH COLD 2% SOLUTION OF TANALITH (SODIUM ARSENATE ANALYSIS N4 (18 Treatments))

Pressure	28 in Hg—40 lb	15 in Hg—40 lb	0—80 lb	10—125 lb	Least difference for significance (5%)
Mean analytical loading	1.74	1.35	1.09	0.80	0.48
Mean distribution ratio	0.35	0.34	0.41	0.48	0.24

absorption percentage, and -0.65 between density and net absorption expressed in pounds of solution per cubic foot of wood. Thus, the adjusted means provide a better measure of the effect of different pressures and temperatures on net absorption. The distribution ratio was variable within treatments, none being significantly different from another.

Results in Table IV show that with similar treatment net absorption by matai was lower than by rimu. This was probably due to the higher density of matai as the kickback ratios of both timbers tended to be similar. Correlation coefficients of -0.77 were calculated between density and net absorption percentage, and -0.57 between density and pounds per cubic foot.

Data in Table V were based on sodium arsenate analyses of matai treated with two per cent. tanalith solution. The pressure combinations used in this series gave gross absorptions of 80 per cent. The differences in loading between initial vacuum and no vacuum treatments resulted from different kickback ratios. It will be noticed in both Tables IV and V that the distribution ratios in matai were low, thus indicating the presence of unpenetrated cores in the wood.

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TRANSMISSION OF HEAT THROUGH WALLS, CEILINGS, AND FLOORS

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Summary

INTRODUCTION

A PRELIMINARY account of some measurements carried out by the Dominion Physical Laboratory on the transmission of heat through wall, ceiling, and floor sections in New Zealand houses was published in this Journal some years ago.¹ Since that time, a considerable extension of this work has been undertaken and a number of improvements in technique and in the scope of these measurements have been introduced. The present contribution describes the apparatus at present employed, and records the results of the measurements obtained.

The rate of heat transmission through the surfaces bounding a room is usually estimated in terms of a coefficient known as the **thermal transmittance** (U). This coefficient represents the number of British Thermal Units (B.Th.U.) transmitted per hour through one square foot of surface area per degree difference of temperature, Fahrenheit, between the air on the inside and the air on the outside of the wall, ceiling or floor.

Two approaches to the measurement of the thermal transmittance of typical wall sections suggest themselves. The one consists in making measurements on walls in houses already erected; the other in building up, in the laboratory, wall sections similar to those to be found in dwellings. The latter method allows of more rigid control of the conditions under which the test is conducted. The field method, on the other hand, is dependent on varying external climatic factors, a circumstance which leads to a much greater spread in the results obtained.

The laboratory method has been used extensively abroad, notably by Rowley and his colleagues at Minnesota² and by Babbitt in Canada.³ The field method, as described in the previous contribution,¹ was developed *ab initio* in the Dominion Physical Laboratory, and was believed at that time to be unique. Subsequently it was discovered that field measurements of a similar nature were conducted in Norway as early as 1922, in small huts specially built for the purpose, in an open field.⁴

Both methods have been used extensively in this Laboratory during the last three years.

EXPERIMENTAL METHODS

The Laboratory Method

The laboratory method was applied in a small room, across the centre of which was erected a partition containing a vertical opening four feet square, to take the wall section under investigation. When

a section had been introduced into this opening, the two portions of the room were completely sealed off from each other and from the exterior. The room was heavily insulated with several layers of soft fibreboard. One side of the partition was kept cold by means of refrigerator coils, while the other side was heated electrically. On each side the air was lightly but thoroughly stirred by fans, while temperature conditions were maintained as constant as was practicable by thermostatic control. The rate of heat extraction by the refrigerator was adjusted by the aid of a back-pressure valve in the low pressure line until the heat extracted from the cold room was a little in excess of that entering. The difference was then made up, as required, by a subsidiary electrical heating system controlled by the thermostat. In this way, a steady temperature could usually be maintained to within a variation of 1°F .

On the heated side of the specimen wall, an open-sided cabinet, provided with heaters and fan, was brought up tightly against the wall, to define an area of the wall, 24in by 24in, on which the heat transfer measurement was actually made. The five sides of this cabinet were heavily insulated and, at the same time, the air temperature inside it and in the heated room surrounding it was maintained as nearly as possible constant and at the same level. This was achieved by means of thermostats of the expanding-bellows type, operating through micro-switches to relays in the two heater circuits. By this means it has proved possible to maintain temperatures in both spaces constant to within about $\frac{1}{2}^{\circ}\text{F}$ over long periods. Heat losses from the cabinet to the surrounding heated room were thus reduced to a negligible amount, and practically all the heat generated in the cabinet passed out through the wall section defined by the perimeter in contact with the open side of the cabinet. Since the heated cabinet covered only the centre portion of the specimen wall, the remainder of which was warmed from the heated room around the cabinet, the lines of flow through this central area could be taken substantially as perpendicular to its surface. If, then, when a steady state had been reached, measurements were made on the amount of heat supplied to the cabinet, and also of the temperature difference established between the air in the cabinet and the air on the cold side of the test wall, all the factors were available for a determination of the coefficient of thermal transmittance through the test wall.

In order to maintain the heating current to the cabinet steady over long periods of time, the energy was supplied by an accumulator battery, kept continuously charged by the aid of a selenium rectifier unit. Further, with a view to eliminating fluctuations of current immediately after switching on, the current from the battery was not switched off when the thermostat operated, but was diverted instead to an equivalent parallel circuit, external to the cabinet enclosure.

With all these precautions, no great difficulty was experienced in maintaining a steady temperature difference, across the wall section, of about 60°F , to a constancy of the order of $\frac{1}{2}^{\circ}\text{F}$ or better, and so to estimate the mean temperature difference to better than one per cent. Thermocouples and a multicircuit galvanometer recorder have been employed throughout these investigations to measure this

temperature difference, as well as to estimate any lack of agreement between the cabinet and the heated room surrounding it.

The overall accuracy of the determinations was limited by the accuracy attainable in estimating the mean heat input into the heated cabinet. Part of this heat was contributed (in some of the experiments) by a continuous supply of current, part by an interrupted supply controlled by thermostat, and part by the action of the fan in stirring the air. This latter part was determined by the following subsidiary test. The fan was driven through a flexible shaft and reduction gearing by a D.C. motor, all external to the cabinet. Voltage and amperage measurements were made on the fan motor, with the fan running at a number of representative speeds. The fan blades were then detached, and these measurements repeated, with motor and drive-shaft running at a similar range of speeds. Two curves were then drawn and, from differences in ordinates of these, a speed-power curve was constructed, giving the net power consumption due to the fan only, when running at various speeds. From this curve, values were read off for use in the main series of experiments.

The estimation of the intermittent heating load was carried out by means of current and resistance measurements, in conjunction with some method of assessing the proportion of the total time during which the current was supplied to the cabinet. In the earlier work, a record was obtained of this fractional time by means of an "on-off" recorder controlled through a relay by the cabinet thermostat. The recorder chart had a speed of five inches per hour, and with interruptions every two or three minutes, it was found difficult to estimate the "on" time to a greater accuracy than about five per cent. Latterly, a somewhat novel and much more satisfactory method was evolved.

Recording of Data Photographically

The foremost improvement that has been made in the experimental accuracy of the work resulted from the introduction of photographic recording of the varying quantities involved. A camera employing 16 mm film and having a wide-angle lens of short focal length was used in the first place to photograph the ammeter in the heating circuit of the cabinet at (approximately) six-minute intervals. Its use was next extended to the photographing of the face of a clock provided with a large seconds hand. This exposure was actuated by means of a system of relays, each time the heating circuit was switched either on or off by the cabinet thermostat.* The switching mechanism also actuated a relay controlling a pair of floodlights so that the panel on which the meter and clock were mounted was strongly illuminated for a brief period commencing a fraction of a second before its exposure to the camera film. After each exposure the film moved on automatically to the next frame. On development it exhibited a series of frames, taken at regular intervals, recording the magnitude of the heating current, interspersed with another series, at more irregular intervals, giving the times (to the nearest second) at which the heating current was switched on or off. A film strip projector subsequently

* For details of this switching circuit, see appendix.

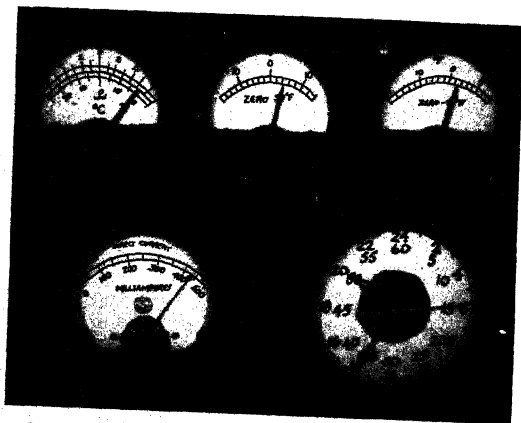


FIG. 1.—Enlargement from a typical film frame showing clock, ammeter, and three temperature indicator dials.



FIG. 2.—The experimental arrangements as used in the field.

enlarged the frame to an appropriate size for reading, and from the readings an estimate was made of the mean current and the mean fractional time during which this current was operating. Later, a further set of three dials was added to the panel, to give indications, by means of resistance thermometers, of the air temperature on the two sides of the experimental wall.

A sample frame from the film, as finally arranged, is illustrated in Fig. 1. Table I sets out a typical set of readings from a series of frames, together with the method adopted for determining a value for the thermal transmittance of the specimen. In Fig. 1 will be seen, reading from right to left in the bottom row, the clock (20h 35m 14s) and the ammeter (432 mA); and in the top row, the temperature of the cabinet air ($78 + 2.8 = 80.8^{\circ}\text{F}$), of the air on the cold side ($50 + 4.4 = 54.4^{\circ}\text{F}$), and of the air in the room surrounding the cabinet ($22 + 5.1 = 27.1^{\circ}\text{C} = 80.8^{\circ}\text{F}$).

TABLE I.

Wall section No. 33.
Date 3-4-49.

Frame No.	Ammeter.		Clock Time.			Temps.		Diff.	Ratio.
	State.	Reading.	H.	M.	S.	Cab.	Cold.	Secs.	
1	on		03	59	38				
2	(on)		04	00	27 $\frac{1}{2}$	92.4	35.1		
3	off	0.441		02	39			181	
4	on			03	50			71	0.71 ₈
5	(on)	0.438		06	28 $\frac{1}{2}$	92.5	35.1		
6	off			06	56			186	
7	on			08	08			72	0.72 ₁
8	off			11	13			185	
9	on			12	26			73	0.71 ₇
10	(on)	0.440		12	29 $\frac{1}{2}$	92.4	35.0		
11	off			15	32 $\frac{1}{2}$			186	
12	on			16	44			72	0.72 ₁
13	(on)	0.435		18	30 $\frac{1}{2}$	92.4	35.1		
14	off			19	46			182	
15	on			20	57			71	0.71 ₉
16	off			24	01			184	
17	(off)	—		24	31 $\frac{1}{2}$	92.3	35.2		
18	on			25	12			71	0.72 ₁
19	off			28	17			185	
20	on			29	29			72	0.72 ₀
21	(on)	0.438		30	32 $\frac{1}{2}$	92.4	35.1		
Means: 0.43 ₈						92.4	35.1		0.72 ₀

Resistance of heater for this current = 4.93 ohms

Area of contact of cabinet with specimen = 2.06 ft $\times$ 2.06 ft = 4.25 sq.ft.

0.438 by meter = 2.41 true amps.

Mean temp. diff. = 57.3°F.

Mean heating rate = 2.41 $\times$ 2.41 $\times$ 4.93 $\times$.720

= 20.0 watts = 70.3 B.Th.U. per hour.

Fan input per hour = 4.4 B.Th.U.

Thermal transmittance (U) = $\frac{70.3 + 4.4}{4.25 \times 57.3} = 0.30$, B.Th.U./sq.ft/hr/°F.

† Regular (approx. six-minute) sequence.

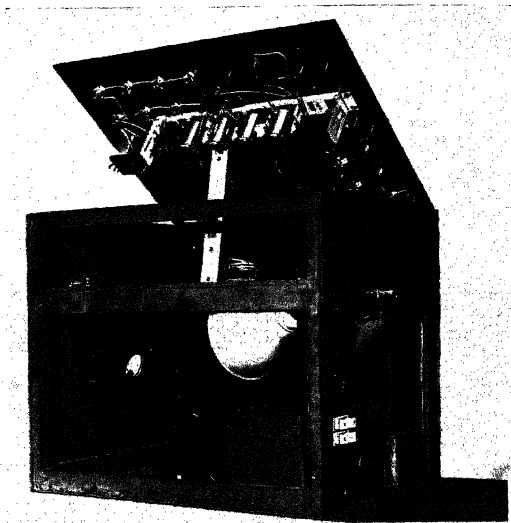


Fig. 3.—Portable control panel and photographic unit: view of interior.

The Field Method

The method of conducting thermal transmittance measurements in actual houses already described in the earlier report¹ has not been substantially altered. The heated cabinet is larger than the one used in the Laboratory, and was designed to span a representative section of a frame construction wall. A typical arrangement of the apparatus is shown in Fig. 2 where the heated cabinet may be seen wedged against an exterior wall. Control circuits and photographic arrangements similar to those above described for laboratory use were incorporated in a portable cabinet which may be seen to the right of the heated cabinet in the figure. The temperature-recording galvanometer and the on-off recorder, as used in the earlier stages of the investigation, are shown also, on the extreme right. An inside view of the control panel and photographic unit, as used in the field, appears in Fig. 3.

Since the whole room is used in the field measurements as the heated surround to guard the heated cabinet, fans and heaters are essential adjuncts to the room equipment. They are shown in the foreground of Fig. 2. The interior of the cabinet was heated by means

of a grid of resistance wire carrying the current and spread immediately in front of a slowly rotating fan with eight-inch blades. This fan was connected by a flexible drive to a motor and reduction gear which may be seen in the left front of Fig. 2.

The most important difference between the methods in the field and in the laboratory result from dependence in the former case on favourable outside weather conditions. It is necessary that low outside temperatures should remain steady for some hours (the length of time depending on the heat capacity of the structure under investigation) in order that stable transmission conditions should supervene. A search for these stable periods was aided by the retaining of the galvanometer recorder and the on-off recorder shown in Fig. 2, even after their major usefulness had been superseded by the film recording method.

RESULTS

The results of all the measurements which have been made, both in the laboratory and in the field, are set out in Table II. Here will be found an abbreviated description of the constructional details of each wall investigated, the description commencing from the outside of the wall and proceeding inwards. The various walls have been grouped roughly, for convenience, under brick, concrete, and frame construction. A certain amount of overlapping within this classification is inevitable.

In Table III will be found a similar assembly of values, representing all data available from overseas on types of construction resembling those investigated in New Zealand. Considerable variations will be found to occur, in some instances, between results for a particular kind of wall as measured by different observers or at different times. This is probably due, in large measure, to differences in the conditions of test, notably in regard to the moisture content of the wall (especially in the case of brick), and to the extent of exposure of the wall to the weather, in field tests.

DISCUSSION

Brick

A study of the results in Table II in conjunction with those in Table III indicates that brick walls in New Zealand have somewhat higher transmittance values than are shown by similar walls overseas. A direct comparison between identical constructions is not possible, but indirect comparisons may be inferred as follows:

4½-inch Solid Wall

For New Zealand 4½ in single, ordinary brick wall (dry), the value is 0.77; while the English Fletton brick is quoted at 0.59. A comparison between the values for English double Fletton walls and double London Stock walls [Nos. 44 (ii) and 45 (i)] under similar conditions suggests that a single leaf London Stock brick wall would have a transmittance in the neighbourhood of 0.56. Interpolation

TABLE II. EXPERIMENTAL RESULTS

Wall No	Wall Type.	Nominal thickness, (in.)	Constructional Details.	Thermal Transmittance.	Footnotes.
A.	BRICK AND BRICK VENEER CONSTRUCTIONS.				
1	(a) Laboratory Tests (1948-49) Brick	4½	Single, red brick (1) damp (2) dry	0.84 0.78	(a)
2	Cavity Brick	11	4½ in. brick; 2 in. sealed cavity; 4½ in. brick. (1) outer leaf dry, inner leaf damp. (2) outer leaf dry, inner leaf dry.	0.46 0.43	
3	Brick Veneer *	11	4½ in. brick; 2 in. sealed cavity; 4 in. x 2 in. studs, lined with: ½ in. softboard.	0.30	
4			½ in. plasterboard.	0.39	
5			½ in. hardboard.	0.41	
6			Building paper and ½ in. hardboard.	0.32	
7	b) Field Tests (1946-48) Cavity Brick	11	4½ in. brick; 2 in. cavity; 4½ in. brick, plastered internally. (1) cavity unventilated. (2) cavity ventilated.	0.42 0.48	
8	Brick Veneer	11	4½ in. brick; 2 in. cavity; 4 in. x 2 in. studs, lined with: ½ in. hardboard (i) cavity ventilated. (ii) cavity unventilated.	0.60 0.53	(b)
9			½ in. p. and p. board, cavity ventilated. (i) structure damp. (ii) structure dry.	0.61 0.54	
10			½ in. fibrous plaster board, cavity ventilated.	0.50	
11			Lath and plaster (½ in.) cavity ventilated. (i) structure damp. (ii) structure dry.	0.60 0.54	
12			As 8(i), but with ½ in. hardboard external to studs, giving an extra, unventilated cavity.	0.44	
13			As 8(ii), but with ½ in. wood straps and ½ in. hardboard lining extra.	0.36	
14	Brick Veneer and Pumice concrete	11	4½ in. brick; 2 in. unventilated cavity; 4 in. pumice concrete plastered internally.	0.32	
B.	CONCRETE AND CONCRETE VENEER CONSTRUCTIONS.				
15	"No-fines" dense concrete	7	6 in. dense aggregate, both faces plastered.	0.54	
16	"No-fines" pumice concrete	9	8 in. pumice shingle aggregate, both faces plastered.	0.28	
17	Concrete cavity block	8	2 in. concrete block; 3½ in. ventilated cavity, 2 in. concrete block, with 2½ in. ribs at 9 in. centres on alternate leaves; both faces plastered.	0.56	
18	Cellular concrete sandwich	9	2 in. cellular; 5 in. dense; 2 in. cellular (no cavity) both faces plastered.	0.33	
19	Pumice concrete inner leaf	11	See No. 14 above.	0.32	
20	Concrete Veneer	10	4 in. dense concrete; 2 in. ventilated cavity; 4 in. x 2 in. studs, p. and p. board.	0.85	(b)

Continued on page 30.

TABLE III. OVERSEAS VALUES FOR THERMAL TRANSMITTANCE OF WALLS

Wall No.	Wall Type.	Nominal thickness. (in.)	Constructional Details.	Thermal Transmittance.	References.	Footnotes (see p. 11)
A. BRICK AND BRICK VENEER CONSTRUCTIONS.						
I Great Britain (1928-48)						
43	Brick	4½	Single 4½ in. Fletton brick.	0.59	5	(a)
44	Brick	9	Double Fletton brick (i)	0.45	5 & 7	(b)
			(ii)	0.40	7	(c)
			(iii)	0.44	5	(d)
			(iv)	0.46	5	(e)
45	Brick	9	Double London stock brick (i)	0.38	6	(f)
			(ii)	0.58	6	(g)
46	Brick	9	Double Fletton, rendered externally (i)	0.42	5	(h)
			(ii)	0.44	5	(e)
47	Brick	9	Double Fletton, plastered	0.43	8	(k)
48	Brick	9	Double brick, roughcast outside, lath and plaster with 1 in. air space internally.	0.28	10	(l)
49	Cavity Brick	11	Double 4½ in. Fletton brick, with 2 in. cavity, unventilated (i)	0.34	5 & 7	(m)
			(ii)	0.35	7	(n)
			(iii)	0.32	5	(o)
50	Cavity Brick	11	As 49 (i) with no ventilation	0.32		
			(ii) with natural ventilation	0.35	5	(p)
			(iii) with forced ventilation	0.42		
51	Cavity Brick	11	As 49 (i) with no ventilation	0.32		
			(ii) with natural ventilation	0.36	5	(q)
			(iii) with forced ventilation	0.46		
52	Cavity Brick	11	Double 4½ in. Fletton brick, plastered (i) with no ventilation	0.30	8	
			(ii) with ventilation	0.34		
53	Cavity Brick	11	Double 4½ in. London stock brick, 2 in. cavity.	0.33	6	(r)
II United States (1937)						
54	Brick	3½	Single common yellow clay brick.	0.499	2	
55	Brick	8	Double common yellow clay brick.	0.355	2	
56	Brick	8	One leaf yellow common clay brick one leaf face brick.	0.406	2	
57	Cavity	9	Two leaves as in (54); 1½ in. cavity	0.274	2	(s)
III Norway (1922)						
58	Brick	14	Double brick, with mortar externally.	0.309	4	
59	Cavity Brick	15½	9 in. brick; 2 in. cavity; 4½ in. brick, plastered externally.	0.250	4	
B. CONCRETE AND CONCRETE VENEER CONSTRUCTIONS						
I Great Britain.						
60	Solid Concrete	9	1 : 2 : 4 mix, cement, sand, Portland stone aggregate	0.37	6	(t)
61	"	9	As 60, York stone aggregate.	0.43	6	(t)
II United States						
62	Solid Concrete	4	Dense concrete	0.632	2	
63	"	6	Dense concrete.	0.585	2	
64	Cavity concrete	10½	4 in. Dense concrete; 2½ in. cavity; 4 in. dense concrete.	0.359	2	

Continued on page 31.

TABLE II (CONTINUED). EXPERIMENTAL RESULTS

Wall No.	Outer Covering.	Inner Lining.	Thermal Transmittance.	Footnotes.
C.	FRAME CONSTRUCTIONS (ALL ON 4IN. x 2IN. STUDDING)			
	(a) Laboratory Tests (1949)			
21	$\frac{1}{2}$ in. cement board	$\frac{1}{2}$ in. softboard	0.34	
22	$\frac{1}{2}$ in. cement board	$\frac{1}{2}$ in. softboard, backed by aluminium foil	0.28	
23	$\frac{1}{8}$ in. asbestos cement board	Wood shavings filling cavity $\frac{1}{2}$ in. hardboard	0.15	
24	"	2in. rockwool bats in cavity, $\frac{1}{2}$ in. hardboard	0.15	
25	"	4in. loose rockwool (9lb./c. ft.) filling cavity, $\frac{1}{2}$ in. hardboard	0.13	
26	"	$\frac{1}{2}$ in. softboard, $\frac{3}{8}$ in. p. and p. board	0.30	(b)
27	"	$\frac{1}{2}$ in. softboard	0.35	
28	"	$\frac{1}{2}$ in. hardboard	0.57	
29	$\frac{3}{8}$ in. asbestos sidings, 2in. overlap	$\frac{1}{2}$ in. softboard	0.38	
30	$\frac{3}{8}$ in. weatherboard	1in. rough lining, scrim and paper	0.33	
31	"	$\frac{3}{8}$ in. p. and p. board	0.47	(b)
32	"	$\frac{1}{2}$ in. softboard	0.35	
33	$\frac{1}{8}$ in. weatherboard, backed by building paper	$\frac{1}{2}$ in. softboard	0.31	
34	$\frac{3}{8}$ in. weatherboard	$\frac{3}{8}$ in. asbestos cement board	0.52	
35	"	$\frac{1}{2}$ in. hardboard	0.51	
36	$\frac{1}{2}$ in. hardboard	4in. wood-shavings-and-cement board; and $\frac{1}{2}$ in. hardboard (no studs)	0.20	(c)
37	(b) Field Tests (1947-48) $\frac{1}{2}$ in. rusticated board	$\frac{3}{8}$ in. rough timber lining; scrim and paper	0.27	(d)
38	"	1in. rough timber lining; scrim and paper	0.32	(e)
39	$\frac{3}{8}$ in. weatherboard	$\frac{3}{8}$ in. p. and p. board	0.41	(b)
40	"	$\frac{3}{8}$ in. fibrous plaster board	0.41	
41	"	Lath and plaster ($\frac{1}{2}$ in.)	0.37	
42	$\frac{3}{8}$ in. asbestos cement board	$\frac{3}{8}$ in. p. and p. board	0.41	

FOOTNOTES TO TABLE II

(a) Relative density of dry brick 2.0.

(b) p. and p. = plaster and pumice sandwich board.

(c) Suitable for partition walls only.

(d) Several layers of wall paper; unventilated cavity.

(e) One layer of wall paper only; lightly ventilated cavity.

TABLE III (CONTINUED). OVERSEAS VALUES FOR THERMAL TRANSMITTANCE OF WALLS

Wall No.	Outer Covering.	Inner Lining.	Thermal Transmittance.	References.	Footnotes.
C.	FRAME CONSTRUCTIONS (All on 4in. x 2in. Studding)				
65	I. Great Britain $\frac{3}{4}$ in. weatherboards and lin. boarding	Lath and plaster	0.28	6	(t)
66	II. United States $\frac{1}{2}$ in. pine lap sidings, building paper, $\frac{3}{16}$ in. fir sheathing	Lath and plaster ($\frac{3}{8}$ in.)	0.220	2	(u)
67	"	$\frac{3}{8}$ in. gypsum sandwich between paper	0.218	2	
68	III. Sweden 1 in. V-jointed vertical boarding, with building paper.	1 in. glass-wool insulating blanket; building paper, $\frac{5}{8}$ in. boarding, $\frac{1}{2}$ in. soft-board	0.18		(v)

FOOTNOTES TO TABLE III

- (a) Fletton brick is a moderately porous brick common in S. E. England. Its relative density is about 1.6.
 (b) See (5), p. 68; (7), p. 85. Mean of values ranging from 0.35 to 0.64.
 (c) Computed for "medium exposure" (6); wall "probably tested in a drier state" than in case of (i).
 (d) Mean of values ranging from 0.39 to 0.46, taken over 13 months.
 (e) Value for days of maximum heat flow.
 (f) London stock is a very porous brick common in the London region. Its relative density is about 1.4 "Average exposure"; presumably tested in dry state as for wall 44 (ii).
 (g) "Thoroughly wet: average exposure."
 (h) Mean of values ranging from 0.39 to 0.43, taken over eight months.
 (k) "Normal Exposure."
 (l) "Scottish Practice."
 (m) See (5), p. 68, Table I; (7), p. 85, Table I; mean of values ranging from 0.27 to 0.50.
 (n) "Computed for medium exposure" (6).
 (o) See (5), p. 74, Table IV; mean of values ranging from 0.28 to 0.35 taken over 13 months.
 (p) See (5), p. 71, Table II; mean values.
 (q) See (5), p. 76, Table II; for days of maximum heat flow.
 (r) From alignment chart, for "average exposure".
 (s) Calculated from Rowley and Algren's experimental data (Ref. 2).
 (t) "Average exposure."
 (u) Similar to New Zealand "rusticating" board.
 (v) Field tests in prefabricated house erected in New Zealand.

between the values for Nos. 54 and 55 points to a value for a United States single $4\frac{1}{2}$ in brick wall of about 0.47.

The common New Zealand brick is much denser than either of these two English varieties, and probably denser also than the American one. It is generally recognised that thermal transmittance is high for bricks of high density, but no figures are quoted in the literature to suggest that any overseas bricks have as high a transmission coefficient as have the New Zealand samples herein discussed.

11-inch Cavity Wall

For a New Zealand unventilated wall, plastered internally, the U value is 0.42. This compares unfavourably with the English Fletton, plastered ($U = 0.30$). A similar wall of London Stock might be expected, on the basis of the values for Nos. 53 and 49 (i), to have a transmittance of about 0.28. The higher value obtained in New Zealand is due no doubt in part to the higher transmittance of the New Zealand brick; but this does not seem to be adequate to account for the large difference noted. The other factor seems to be the higher rate of cavity ventilation. The British values for cavity brick (wall 50) are 0.32, unventilated, and 0.35, ventilated (with forced ventilation raising this to 0.42); and by comparison, the New Zealand values (wall 7) are 0.42, unventilated, and 0.48, ventilated. From this the conclusion is reached that the ventilation in the cavity of the New Zealand wall was considerably greater than in the naturally ventilated British wall, and possibly was approaching that in the wall subjected to forced ventilation. The effect of this unduly high draught in New Zealand wall cavities seems to be the chief cause of the large transmittance, as compared with British values for similar constructions.

The value calculated herein for a similar American wall $U = 0.274$ (No. 57) indicates a still lower transmission value, in spite of the fact that both leaves of the brickwork are a little thinner and the cavity a little narrower than is the practice in either Britain or New Zealand.

Some comparison with the Norwegian values may also be derived as follows. On the basis of 0.59 for a single ($4\frac{1}{2}$ in) brick wall (No. 43) and 0.40 for a double (9 in) wall of similar brick (No. 44) (ii), it may be inferred that a triple ($13\frac{1}{2}$ in) British solid wall would have a U value in the neighbourhood of 0.30, a value in reasonably close agreement with the Norwegian figure (No. 58). Again, on the basis of 0.30 for an 11 in cavity wall [No. 52 (i)], plastered and unventilated], it would appear as if a British Fletton brick wall constructed closely to resemble the $15\frac{1}{2}$ in cavity wall (No. 59) in Norway would have a U value closely in agreement with the 0.250 actually listed from Norway. The New Zealand values, on a similar basis, would almost certainly be markedly higher.

Concrete

The thermal conductivity of a sample of solid concrete depends mainly on the nature of the aggregate from which it is made. Overseas literature quotes a wide range of values, from as low as 6.5 up to as

high as 16.4 units per inch. The values most frequently employed for calculations lie between 7 and 8 units per inch. A wall of solid, dense concrete would thus need to be at least 12 in. in thickness before its transmittance would be reduced even to the neighbourhood of 0.40, the figure exhibited by a considerable number of other structures commonly employed. Under these circumstances, it was not considered necessary to make any transmittance tests on ordinary concrete walls in the present series of measurements. Instead attention was directed to such modifications of ordinary concrete as "no-fines" and cavity block constructions and to cellular and pumice concretes. The values found for samples of the former group (No. 15 and No. 17) are disappointingly high; while the sample of concrete veneer construction (No. 20) provided the highest value of any structure actually investigated in the field in New Zealand. On the other hand, the cellular concrete (No. 18) and pumice concrete structures (No. 16 and No. 19) yielded the lowest values of any modern type of New Zealand wall, excepting only those in which softboard or other insulating material has been introduced into the structure.

Veneer Constructions—Brick and Concrete

No measurements seem to have been made abroad on any structures closely resembling New Zealand brick—or concrete—veneer houses. Rowley and Algren² give figures for two brick veneer structures, distantly resembling a New Zealand type; but in both cases, a layer of insulation has been incorporated. The U values are in consequence very much lower (0.104 and 0.136) than anything encountered in New Zealand.

An inspection of the actual figures obtained for New Zealand veneer constructions, in comparison with overseas values for ordinary brick and concrete constructions, reveals the important fact that practically all New Zealand veneer constructions have an extremely high thermal transmittance. The only exceptions are those constructions in which some insulating material (or an extra dead air layer) has been incorporated in the structure. These high values, in the case of brick veneer, are in part due, as has already been mentioned, to the high transmittance values of New Zealand bricks. But again the main cause seems to be the excessive rates of cavity ventilation prevalent in New Zealand houses constructed during recent years. Attention has already been drawn to the consequences of this New Zealand practice in an earlier communication from Dominion Physical Laboratory,³ and further work on the upper limit of ventilation necessary to obviate the risk of dry rot in stud timbers, substantiates the previous conclusion that very low ventilation rates are quite adequate to cope with this fault. A full report on this subject will appear in this Journal shortly.

Frame Constructions

Wood frame methods of wall construction in different parts of the world vary considerably in detail. Apart from the general, but by no means universal, tradition of employing 4 in. by 2 in. timber studding, there is little resemblance in detail between New Zealand

types of wall construction and those overseas ones for which any thermal transmittance data are available. The few overseas values assembled in Table III under this heading provide only a very meagre basis for comparison with the abundance of data assembled in Table II for New Zealand structures. Rowley and Algren² record much data on frame constructions, presumably typical of American building practice; but with the exception of the two types listed in Table III, all the examples quoted by them contain one or more layers of some insulation material, and have in consequence much lower transmittance co-efficients.

From this comparison, the fact emerges that the New Zealand values obtained from structures actually used in dwellings are in every case appreciably higher than any values available from overseas. The only laboratory results which approach these overseas values relate to structures in which softboard or other insulating material has been incorporated. The field work on frame constructions thus reveal the same inferiority, as compared with overseas types, as has already been noted for brick and veneer constructions. Since the vast majority of modern houses in New Zealand are of the veneer or the frame construction types, it appears that in most of them protective measures against external cold fall considerably short of those adopted in overseas practice.

STANDARDS OF THERMAL TRANSMITTANCE FOR DWELLINGS

In recent years, considerable attention has been directed overseas to the formulation of standards of thermal transmittance suitable for dwellings. In Great Britain, the Burt Committee, in 1944, in its monumental report on "House Construction"¹¹ suggested that the following maximum values for heat transmission co-efficients would prove economical:—

"a. In houses in which the [heating] apparatus allows of full control over the heat output.

External walls of living room	U not to exceed 0.15
External walls of rest of house	" " " 0.20
Ground floor	" " " 0.15
Roof and top floor ceiling	" " " 0.20

"b. In houses in which the apparatus does not allow of full control over the heat output.

External walls of living room	U not to exceed 0.20
Ground floor	" " " 0.15
Roof and top floor ceiling	" " " 0.30 "

In Canada, a standard of thermal insulation for dwellings is laid down by the National Building Code, prepared under the joint sponsorship of the Government Department of Finance (National Housing Administration), and the National Research Council of Canada. Except in buildings specifically designed for summer occupation only, the Code allows for a maximum thermal transmittance co-efficient for walls of 0.25 and for ceilings 0.35.¹² These values seem to be somewhat conservative, in relation to the severity of the Canadian climate; for Babbitt¹³ referring to a house having $U = 0.25$ for walls and 0.31 for roof and ceiling, says "Such a house would never be used in Canada".

There appear to be no generally accepted insulation standards for housing in the United States of America. A cross-section of current practice in that country is probably indicated in the comprehensive report on "Thermal Conductivity of Building Materials" by Rowley and Algren.² They list transmittance values for over 80 types of wall constructions, ranging from 0.07 up to 0.69, with a mean of 0.26, and concentration of values around 0.15 and 0.22.

Transmittance values suitable for dwellings in Australia have been given by Barned¹⁴ as follows:—

External walls	.. ..	0.25 to 0.30
Floor	.. ..	0.30 to 0.40
Roof and ceiling	.. ..	0.30

Norwegian traditional practice (25 years ago) may perhaps be judged from the range of values given by Kolflaath¹ for 34 typical wall sections, *viz.*, from 0.133 to 0.378, with a mean of 0.236.

The Swedish figure (0.18), obtained in measurements on a pre-fabricated house imported into New Zealand from Sweden, supplies the only available information bearing on relevant current practice in that country.

The field data assembled for New Zealand houses in the course of the present investigation range from 0.27 to 0.65, with a mean of about 0.45. It is significant that the lowest value met with was in a house of traditional frame construction (weatherboards, with rough timber lining and an airtight cavity). Such construction is typical of the majority of dwellings erected in New Zealand up to about twenty years ago. The general consensus of opinion is that such houses are reasonably well suited to the New Zealand climate, being comfortably warm in winter. A very different opinion is commonly expressed as to the warmth or coldness of houses of almost any of the types erected recently in New Zealand. This general impression is borne out by the measurements herein reported on houses built in recent years. It appears that the traditional house of twenty years ago set a reasonably satisfactory standard of thermal transmittance in relation to the climate peculiar to a large part of New Zealand.

In an attempt to formulate a standard of thermal transmittance for New Zealand dwellings, it may be desirable to take some account of the extremes of climate in the far north and in the south. These climatic contrasts are differentiated in a recent classification¹⁵ which divides New Zealand into five climatic zones, the division being based on estimated annual degree-day values for typical stations throughout the country. In the north (zone 1), the degree-day value is below 1,800 per year, while at the other extreme, zone 5 has upwards of 3,600 degree-days per year. The central half of New Zealand falls into the middle zones (2 to 4), the climate being in general somewhat milder than in the south of England. It is appropriate, therefore, that a standard of thermal transmittance for this part of New Zealand should be lower than that laid down by the Burt Committee for Britain. On the other hand, the mean degree-day for England (4,200) is commensurate with that for New Zealand zone 5 (over 3,600). The

Burt recommendations might therefore very well apply to this coldest zone of New Zealand; while at the same time a lower standard would suit the milder north country.

In the light of these considerations, it is suggested that the thermal transmittance values given in Table VI should be accepted as representing a reasonable standard for dwellings in the various climatic zones in New Zealand.

TABLE VI. PROPOSED NEW ZEALAND STANDARDS OF THERMAL TRANSMITTANCE FOR DWELLINGS

(Maximum permissible heat loss in B.Th.U./sq. ft./hr./°F)

Annual degree-days	Zone 1	Zones 2 to 4	Zone 5
	1,800	1,800 to 3,600	3,600
Outside walls of living-room	0.30	0.25	0.20
Outside walls of other rooms	0.35	0.30	0.25
Ceiling and roof	0.35	0.30	0.25
Floor	0.30	0.25	0.20

It will be seen that the standard for walls in the central zones is commensurate with the values found for walls in the traditional New Zealand house, but that values for most of the recent housing types reported in this paper are considerably in excess of these standards. Even the less exacting standard suggested for the north is attained only by special constructions in which some kind of insulating material is incorporated.

PRACTICAL APPLICATIONS OF THESE STANDARDS

Treatment of Walls

If the standards of thermal transmittance of walls recommended in Table VI are to be attained in New Zealand dwellings, recent methods of construction must be modified considerably.

Two possible courses are open. Either building materials having much better thermal insulating properties must be utilised, or insulation must be introduced into present structural types. (The third alternative, a considerable increase in thickness of the materials now in use, is economically impracticable at the present time.)

If the present types of frame construction are to be retained, with linings of either fibrous plaster or plaster-and-pumice sandwich board, the extra insulation needed may be incorporated within the stud space. This insulation may take the form of batts, sprung into place between the studs, or blanket insulation laid in place between the studs before affixing the lining, or granular material poured into the cavity from above, after affixing the lining. The most suitable material in any of these forms is one or other of the various woolly mineral materials known as glass-wool, mineral wool, rock wool, slag wool, etc. This material is inert and non-inflammable, and does not attract moisture.

As an alternative, the extra insulation for frame constructions may be added on to the interior. Either the room may be lined with softboard (a method not generally to be recommended for other reasons, such as the fire hazard), or a layer of hardboard or plywood may be attached by wood straps to the inner surface of the walls, leaving a narrow dead-air space between the two surfaces. (See e.g., wall No. 13, Table II; the value for an unventilated brick veneer wall, lined with plaster-board, etc., and strapped and lined in this way with hardboard would have a U value of about 0.33; the same internal treatment to wall No. 42 would produce a value about 0.28).

The other course available is to employ one of the newer types of construction, in which the chief material employed has itself a moderately low transmittance co-efficient. Most promising among these is "no-fines" pumice concrete, an 8 in. wall of which has given 0.28, while a 9 in. wall would in all probability give not more than 0.25, the standard suggested for living-room walls in the central zones of New Zealand.

The value of pumice concrete as an inner lining is emphasized by the results for wall No. 14. ($U = 0.32$.) Had the inner leaf here been of "no-fines" pumice concrete, the value for the wall would almost certainly have been a little below 0.30.

Another promising type of construction arises from the development of cellular concrete, used as a permanent shuttering for a structural core of dense concrete. Wall No. 18 was one of the earliest examples of this construction to be erected in New Zealand. Its U value (0.33) has no doubt been considerably improved by later modifications, such as by increasing the cellular thickness to 3 in. for each leaf, the dense core being reduced, without undue detriment, to 4 in. Such a wall would have a U value very close to 0.25.*

No doubt, as the desire to improve the thermal transmittance of New Zealand houses becomes more general, further new materials and methods of construction will be proposed. As such new ideas take shape, the Dominion Physical Laboratory plans to investigate the thermal properties of the proposed constructions and to publish results, as opportunity offers.

Treatment of Ceilings

The standards of thermal transmittance, above proposed, include value for ceilings and floors. Little mention has so far been made of these in the present report. The results in Table VII are the only experimental values for New Zealand ceilings available for comparison with these standards, these values being quoted from a previous report⁹. They were all obtained in recently-erected houses with pitched roofs, in which the attic space, as is usual, was substantially

* It should be noted here that both pumice concrete and cellular concrete, as normally cured, are subject to considerable dimensional change with change in moisture content, a property which renders them very liable to cracking, and also requires the use of special rendering and plastering mixtures to match this dimensional change. This defect appears to have been largely overcome abroad, and investigations aimed at overcoming it are in progress in the Dominion Physical Laboratory.

ventilated. The temperature difference on which each result is based is the difference between the temperature maintained inside the room and that measured (in a steady state) in a sheltered locality, four feet above ground level, outside the house (and not above the roof). This technique, though not fundamentally sound, is justified insofar as it simplifies the application of the results to normal practical procedure. It should be noted that the values apply to winter night conditions, when heat is escaping upwards from the house, and not to summer day conditions, when heat is normally flowing downwards from the outside.

TABLE VII. THERMAL TRANSMITTANCE VALUES FOR CEILINGS
IN NEW ZEALAND HOUSES

Fibrous plaster and tiles	0.60
Lath and plaster and tiles	0.60
Softboard and tiles	0.40

Since heated air tends to rise, the temperature of the ceiling of a heated room is usually warmer than the walls. Hence heat losses from a house are usually greater through the ceiling than through a corresponding area of wall. Also with the modern tendency to erect houses with a stud height of not more than about eight feet, the wall area has become smaller, and is also smaller in proportion to that of the ceiling. It is therefore of still greater importance in modern houses to give careful consideration to the insulation of ceilings. This is less

TABLE VIII. U VALUES RESULTING FROM INTRODUCTION OF INSULATION
INTO CEILINGS

Method		For a ceiling having U value initially	
		0.40	0.60
1	Extra layer of $\frac{1}{2}$ in softboard in contact with ceiling (either above or below)	0.25	0.32
2	Extra layer of $\frac{1}{2}$ in softboard nailed over joists giving 4 in air-tight cavity	0.20	0.24
3	1 in mineral wool (flocculated or granulated) poured on to ceiling between joists	0.17	0.20
4	1 in mineral wool blanket laid over ceiling between joists	0.16	0.19
5	2 in mineral wool (in batts) laid over ceiling between joists	0.10	0.12

difficult to achieve than in the case of walls, except perhaps in houses already erected and having flat roofs. Methods by which insulation may readily be introduced into ceilings are suggested in Table VIII, where also are tabulated the (calculated) transmittance values for the various methods suggested as applied to typical ceilings from Table VII.

As will be seen, Method 1, as applied to a plaster ceiling, is adequate to conform to the standard set for Zone 1, and Method 2 for all other zones. It should be pointed out, however, that an important part of the cost of installing insulation arises from the labour charges, so that the extra cost for the superior insulation is not proportionally higher. Also the installation of ceiling insulation is almost invariably a very economical measure, if reckoned in terms of the value of the fuel saved during the life of the house.

Treatment of Floors

The only type of floor commonly employed in New Zealand dwellings is the tongued and grooved board floor on timber joists, with ample under-floor ventilation to ensure the continued dryness of the timber. The U value for such a floor is about 0.40. Since most of the heat loss through such a floor results from this very necessary ventilation, it may be more economical, in planning a new house, to design a solid floor built directly on the ground, rather than to attempt to insulate a ventilated timber floor. A recommendation along these lines is made in the Egerton Report,¹⁶ in which the value quoted for one inch (nominal) tongued and grooved boarding on timber joists, ventilated underneath, covered with linoleum, is 0.35; while for one inch (nominal) wood block on concrete on ground, the value is 0.15.*

One such floor has been investigated in New Zealand. It consisted of four inches of dense concrete, underlaid by nine inches of shingle, and covered with a half-inch of bitumen flooring. The U value was 0.14. This type of floor is thus a distinct improvement on the traditional New Zealand floor from the heat loss angle. At the same time, the cost is liable to be appreciably less, especially in comparison with an insulated board and joist floor, provided the site is suitable.

If, however, it is desired to insulate a traditional timber floor, a number of practicable methods present themselves. Table IX offers some suggestions for this, together with the calculated U values resulting.

Once again, some of the values are much superior to the standard, but the extra cost of the better insulation will probably be more than compensated for by the extra saving in fuel costs. This does not apply with quite so much force as in the case of ceilings, since internal temperatures tend to be lower near the floor than near the ceiling. However the general comfort of a house is distinctly improved when the floor feels warm to the feet, a result which is assured if the floor is insulated.

*As the Burt Report points out,¹¹ "normally the temperature difference across the floor (air inside to earth) will be less than that across the external wall (air inside to air outside). The true value of U for the solid ground floor is adjusted so that, in calculating the heat loss through the floor, these two temperature differences can be assumed to be the same". The value for the New Zealand floor, quoted above, has been adjusted in the same manner.

TABLE IX. U VALUES FOR AN INSULATED FLOOR HAVING A U VALUE (UNINSULATED) OF 0.40

$\frac{1}{2}$ in softboard, cut and nailed to underside of floorboards between joists	0.25
$\frac{1}{2}$ in softboard, nailed under joists and sealed to give an air-tight cavity	0.20
$\frac{1}{2}$ in hardboard, nailed under joists and sealed to give an air-tight cavity	0.28
1 in mineral wool blanket, cut and nailed to underside of floorboards between joists	0.16

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APPENDIX

AUTOMATIC RELAY CIRCUIT FOR RECORDING CAMERA OPERATION

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Summary

An automatic switching circuit is described for converting a signal, due to both make and break of a thermostat circuit, to a complete on-off cycle at each signal. The duration of the on-off cycle is independent of the originating signal and is easily adjustable.

This circuit was devised for the operation of a camera for which a complete on-off cycle was required, and which was used to record the readings of several variables in an experiment. The camera and lights could not be energized continuously. Since records were required of exact timing, a clock with a seconds sweep hand was photographed at the same time as the other variables.

Three relays were used, as shown in Fig. 4. Relays A and B were standard P.O. type 3,000, with double windings of 2,000 ohms each. Relay C is also 3,000 type, with with a single 6,000 ohm winding. One winding of both A and B is shorted, when at rest, through its own contacts, so that it provides a delayed action on pick-up only.

An electrical interlocking is also provided to ensure correct operation (note a_3 - a_4 and b_3 - b_4). The interval of time (several milliseconds) between drop-off of one relay and pick-up of the other is used to charge the condenser connected across relay C.

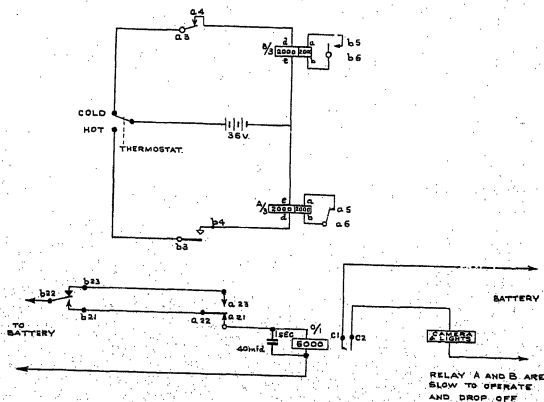


Fig. 4.—Diagram of automatic relay circuit.

OPERATION

- (1) Thermostat moves from "cold" to hot".
- (2) Relay B drops off and contact b_{21} is connected to battery which energizes relay C and condenser. This operates lights and camera.
- (3) Relay A then picks up and disconnects relay C circuit by opening contacts a_{21} .
- (4) Condenser holds relay C for delay of 1 sec. and then drops off, to be ready for next signal from thermostat.

The duration of the on-off cycle of relay C is adjustable by altering the electrical circuit to suit. This could easily be done by incorporating a variable resistance suitably calibrated as a shunt across the condenser.

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EARTHQUAKE ORIGINS IN NEW ZEALAND DURING THE YEAR 1949

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Summary

Origin times, epicentre positions, and the maximum reported felt intensity of all earthquakes located in the New Zealand region during the year 1949, are tabulated below.

The epicentres are also shown graphically on the accompanying map, with the exception of seven, which are outside the boundary of the map. Isoseismal maps are given for two of the most important shocks during the year.

Origin Time. (G.M.T.)*			Epicentre :		Max. Felt Inten- sity. (M-M).	Origin Time. (G.M.T.)*			Epicentre :		Max. Felt Inten- sity. (M-M).
1949	h.	m.	Lat. S (deg.)	Long. E (deg.)		1949	h.	m.	Lat. S (deg.)	Long. E (deg.)	
Jan.						Feb.					
10	15	44	40.0	173.4	—	21	19	26	37.4	176.8	—
11	14	13	46.4	172.5	—	22	23	17	39.5	179.2	—
12	04	05	37.6	177.1	—	27	10	43	40.5	177.5	slight
12	05	58	39.8	176.8	II	28	22	10	42.4	173.2	—
15	04	42	39.3	175.1	III	Mar.					
20	00	03	38.8	176.0	I	5	00	26	38.9	175.3	II
22	09	25	39.0	175.9	—	5	03	40	38.3	176.5	—
23	13	08	41.5	174.1	—	6	11	22	38.7	176.1	II
24	13	06	40.9	172.8	II	6	16	45	38.7	176.1	II
26	03	50	37.9	176.4	—	7	20	17	40.6	176.7	III
26	16	13	40.1	175.0	IV-V	15	20	03	40.7	175.8	—
29	09	20	38.7	175.9	—	16	03	13	39.0	177.6	III-IV
29	14	20	37.5	178.5	—	16	17	07	40.5	173.0	—
29	20	21	43.3	171.6	II	17	08	46	36	179	—
29	21	12	40.8	172.1	V	17	12	15	36	174	III
30	23	22	40.8	172.1	V	21	23	05	43.4	173.4	II
31	15	37	40.4	174.4	I	22	00	48	40.4	173.3	—
Feb.						23	11	30	36	174	III
2	18	02	42.5	172.9	II	25	12	26	41.9	173.7	—
3	19	21	42.5	172.9	III	Apr.					
4	15	24	39.7	174.4	—	2	12	11	38.2	176.35	—
6	18	19	37.7	177.0	II	3	00	14	40.0	174.2	—
6	18	30	37.8	177.2	I	5	15	51	41.9	174.1	III
6	18	42	37.4	177.4	II	6	23	46	35	179½	—
6	18	44	37.4	178.0	III	9	21	42	36½	178W	—
6	23	05	37.5	177.2	—	14	18	58	41.4	174.2	III
8	05	08	39.3	176.3	—	14	23	58	43.6	175.2	—
9	11	32	40.0	175.0	I	28	04	02	41.7	175.0	—
9	17	31	39.9	174.2	VI	30	20	52	39.1	177.9	—
13	09	32	38.9	175.2	II	May					
13	18	24	34.0	178.0W	IV	3	06	25	41.0	174.8	III-IV
14	09	20	37.3	175.7	II?	3	17	07	42.6	173.0	IV
14	10	20	37.3	175.7	II?	3	20	00	44.6	169.2	—
14	16	29	37.3	175.7	III?	5	15	30	41.3	172.7	—
16	09	45	37.3	175.7	?	6	19	02	40.5	174.2	—
16	12	00	37.3	175.7	?	8	18	16	38.4	176.7	III
16	20	53	40.4	176.0	II	12	18	25	39.8	174.6	—
17	10	25	39.6	177.0	—	14	12	22	39.0	174.7	—
19	10	24	38.5	176.6	—	16	09	15	39.3	174.7	—
21	17	56	40.0	175.7	III	17	02	11	39.1	175.8	—
21	18	06	40.2	175.7	II	17	09	57	42.4	172.9	—

Origin Time. (G.M.T.)*			Epicentre :		Max. Felt Inten- sity. (M-M).	Origin Time. (G.M.T.)*			Epicentre :		Max. Felt Inten- sity. (M-M).
1949	h.	m.	Lat. S (deg.)	Long. E (deg.)		1949	h.	m.	Lat. S (deg.)	Long. E (deg.)	
May						Aug.					
19	07	54	42.6	172.9	—	1	12	55	41.6	174.3	—
20	09	41	38.7	176.2	—	2	03	47	42.2	174.5	—
22	01	22	39.5	177.0	—	6	13	19	45	168	IV
22	10	11	38.5	176.9	—	6	22	31	45	168	II
24	22	47	38.2	176.5	—	7	22	10	38.9	175.7	—
27	05	19	43.3	177.4	—	8	00	17	39.3	175.0	—
27	08	54	45.5	167.0	VI	8	06	27	36	175.4	II
29	00	23	39.1	176.0	—	8	21	26	39.3	174.6	III
29	18	12	39.7	174.2	IV-V	8	23	33	40.6	174.4	—
29	21	49	38.9	176.2	—	9	07	11	41.4	171.9	—
Jun.						10	19	29	41.3	173.8	—
3	10	05	37.8	174.9	II	11	13	34	41.4	173.0	—
7	03	28	40.0	175.1	—	18	01	54	40.9	172.7	III
7	18	28	37.0	176.1	—	24	16	45	41.6	173.2	—
8	11	17	38.8	176.2	—	25	09	22	36.6	179.1	II
11	05	16	36.2	176.3	—	26	01	06	40.9	173.3	—
11	20	26	37.8	174.9	II	26	13	59	39.7	178.6	—
12	09	27	41.1	172.1	III	28	19	30	41.4	174.5	—
14	16	05	39.9	175.1	—	28	22	43	40.5	174.4	—
15	16	19	43.5	172.4	IV	29	22	44	41.5	172.9	—
16	14	01	39.2	174.7	—	31	21	29	41.1	172.2	III
18	08	36	39.5	175.5	—	Sep.					
19	01	55	39.0	174.9	—	1	13	10	40.6	174.4	—
20	04	35	35	176.4	—	3	04	08	39.5	174.4	—
22	00	40	40.0	174.8	IV	5	11	43	39.7	174.7	—
23	08	12	39.3	174.9	—	6	10	47	42.15	172.7	—
24	22	14	38.9	175.9	—	6	16	09	41.6	173.7	—
27	08	06	37.55	177.05	—	8	11	51	40.6	173.8	—
28	14	43	40.2	175.6	I	10	20	50	38.5	176.9	II
Jul.						11	20	23	38.6	176.6	II
1	16	21	39.2	176.6	I-II	13	01	56	38.4	175.5	—
2	11	56	39.4	179.3	—	14	09	40	41.1	172.7	II
3	05	39	40.8	174.1	—	14	22	30	38.7	176.2	II
3	08	02	38.0	176.2	—	14	22	36	38.8	176.1	I
4	06	09	41.1	175.4	IV	15	07	38	41.2	175.8	—
5	09	28	42.1	174.2	—	16	00	26	40.0	176.7	II
6	06	18	40.5	174.1	—	16	05	45	39.25	173.3	IV-V
11	20	21	39.9	172.5	—	17	09	36	42.4	174.8	—
12	04	22	39.7	176.5	—	20	07	20	41.2	172.3	—
12	05	02	37.9	176.4	—	26	02	15	39.4	173.7	V
18	23	07	40.8	172.7	II	27	17	13	42.05	172.6	V-VI
19	05	12	40.8	172.7	II	27	17	24	42.05	172.6	—
19	17	07	39.0	175.8	—	27	17	27	42.05	172.6	—
20	12	03	38.8	175.8	—	27	17	35	42.05	172.6	—
20	22	34	40.2	174.0	—	27	17	39	42.05	172.6	—
21	15	11	40.1	173.8	II	27	17	58	42.05	172.6	—
22	15	27	40.1	174.8	—	27	18	24	42.05	172.6	—
24	10	31	40.2	173.8	—	27	18	59	42.05	172.6	—
25	21	37	38.9	177.0	—	27	20	49	42.05	172.6	—
27	01	29	38.4	175.7	—	28	22	55	42.6	173.3	—
29	12	23	38.9	175.6	—	29	00	25	39.0	175.4	—
30	15	04	39.2	176.7	—	29	07	22	42.2	172.8	—

Origin Time. (G.M.T.)*			Epicentre :		Max. Felt Inten- sity. (M-M).	Origin Time. (G.M.T.)*			Epicentre :		Max. Felt Inten- sity. (M-M).	
1949	h.	m.	Lat. S (deg.)	Long. E (deg.)		1949	h.	m.	Lat. S (deg.)	Long. E (deg.)		
Sep. 30	08	29	40.7	174.0	—	Nov.	15	04	22	40.9	174.2	I
Oct.							16	13	22	40.1	174.5	—
1	01	18	42.1	172.6	—		16	15	57	40.4	174.2	—
1	08	32	42.3	172.9	—		19	15	01	41.5	173.4	—
3	11	42	40.9	174.6	IV		20	11	01	42.2	172.9	—
3	17	58	45.8	167.6	III		22	00	51	29	178W	III
8	06	49	40.0	175.1	II-III		23	11	59	40.3	176.2	III-IV
10	16	52	41.15	172.7	IV		23	12	24	40.0	174.1	—
11	11	37	33	178½W	—		23	14	54	40.2	175.6	—
11	19	23	41.3	175.6	I		24	05	06	40.3	175.1	—
11	20	25	40.9	172.4	—		24	06	02	41.2	173.7	—
16	00	32	41.5	172.2	IV	Dec.						
17	23	49	41.1	172.5	—		1	17	07	41.2	174.5	—
19	18	43	45	168	I		3	16	36	40.6	173.6	—
24	17	15	40.5	171.8	—		5	16	49	40.5	173.8	—
24	17	16	41.3	172.4	—		7	18	37	38.55	176.2	III
26	07	39	37.7	176.2	IV		9	09	30	43.1	171.3	—
26	09	01	37.7	176.2	IV		14	03	56	41.0	174.1	—
28	00	21	40.3	174.1	—		18	05	39	34	179½	IV
29	07	00	43.2	173.15	II-III		18	09	35	39.25	175.95	IV+
29	08	38	39.9	175.0	—		19	07	07	42.2	172.8	—
30	23	55	34	178W	—		19	08	53	39.0	176.6	—
31	10	26	40.1	174.2	—		19	13	55	40.9	173.0	—
Nov.							21	04	09	42.6	173.3	—
7	01	28	41.5	174.4	—		22	13	13	41.35	172.3	V
8	15	13	40.4	176.0	III-IV		22	13	17	41.3	172.3	—
9	16	08	41.3	173.0	—		24	09	24	38.9	175.6	—
9	16	39	42.5	172.9	—		27	22	27	41.2	172.1	—
9	22	23	45½	167	III?		29	09	51	41.2	172.1	—
12	12	11	42.3	172.7	—							

* G.M.T. (Greenwich Mean Time) is 12h.
00m. behind New Zealand Standard Time.

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VOLCANIC ACTIVITY AT MT. RUAPEHU FROM AUGUST TO DECEMBER, 1945

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Summary

The activity of Mt. Ruapehu when in eruption from August to November, 1945, is described and mechanism of eruption is discussed. Maps, photographs, and sections illustrate the various stages of eruption.

INTRODUCTION

The earlier stages of the 1945 eruption of Mt. Ruapehu have been described by Reed (1945), who reviewed previous activity and briefly described the geology of the mountain, and by Oliver (1945). These accounts dealt with the progress of the eruption from March, 1945, when unusual activity was first noted, to July, 1945.

On 8 August, 1945, the writer (at first in company with Mr. H. E. Fyfe, New Zealand Geological Survey) began observations, using the Chateau Tongariro as a base. During August a geophysical party made preliminary magnetometric and microseismic investigations. The writer visited the crater to observe its activity from September to November whenever weather and climbing conditions permitted. During November geophysical equipment was installed at the Chateau to record seismic and magnetic activity, and at the end of November, Mr. J. Healy, vulcanologist at New Zealand Geological Survey, took charge of further investigations.

NARRATIVE OF ACTIVITY

July: Between Oliver's visit and the beginning of August, visitors to the mountain reported that the intensity of the emission, chiefly steam and some gas, increased throughout the month and that infrequent heavy explosions occurred at irregular intervals. These explosions threw boulders, up to several tons in weight, some hundreds of yards from the crater* on to the surrounding ice, the impact making large pits

*In this account, references to the crater apply to the basin formerly containing the crater lake, and not to the new crater formed by the present eruption, which will be referred to as the "vent."

where they fell. Smaller stones and pebbles were thrown as far as half a mile. The boulders were hot, and some were reported to be hot enough to cause vapour clouds for two days after they fell.

The plug-dome ("tholoid" described by Oliver) grew until it completely filled the crater; and the vent (described by Oliver, 1945) was enlarged by bursts of steam which hurled rocks hundreds of feet into the air.

August: The emission of steam further increased during August. On 17 August, the first unobscured view of the crater was obtained.

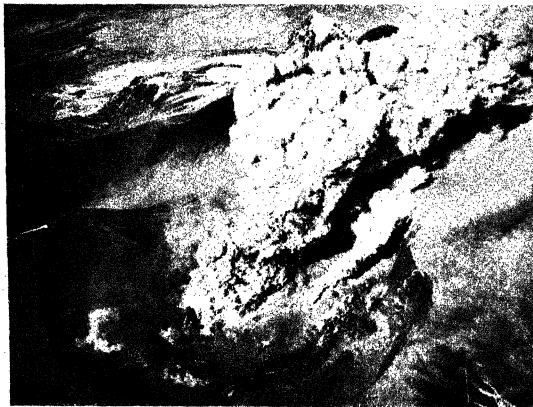


Fig. 1—Aerial photograph of the summit of Mt. Ruapehu showing development of main features of the crater. View from north. A, B, C, ring fault, later developed further. Two vents are seen, the third being obscured. 22 August, 1945. —Photo RNZAF

The still-growing plug-dome occupied the whole of the crater except for a strip of mud a chain wide in the north-west quadrant. The ice walls present on three sides of the crater were ash-covered and pitted with boulder holes. On the east side the thin rock rim was bare. The bouldery surface of the plug-dome was nearly flat except for low cones surrounding the three principal vents. The largest vent was about 10 chains in diameter and near the east edge of the plug-dome. A small central vent on the edge of the east vent was a few yards in diameter. The third, a little larger than the central vent, was on the west side of the plug-dome. In the north-west quadrant was a narrow ring fissure (see Fig. 1). These main features are also shown on a plan and section (Fig. 2 (4A and 4)). The main activity was from the east vent, from which ash-laden steam was erupted continuously. Frequently bursts of steam carried boulders up to 1,000 feet into the air. The majority of these boulders fell back on to the surface of the plug-dome, but some that were projected slightly laterally fell on the ice in the basin surrounding the crater. These bursts of ash-laden steam that carried the

boulders became highly charged electrically, and lightning discharges occurred between the ascending ash cloud and the surface of the plug-dome, accompanied by sharp crackles of thunder. Ash-free steam issued from the central and west vents, from the fissure, and from many cracks and crevices in the surface of the boulder-strewn plug-dome.

On 22 August, the activity reached a peak not exceeded till November. A tremendous cloud of ash-laden steam was carried westwards, and a fall of grey dust was observed at Wanganui, 55 miles away. The colour of the continuous heavy bursts was variable; at times it was of a pinkish tinge and at other times it was yellowish; but for the most part it was dark grey. In the crater itself the central vent emitted mainly a yellowish steam, and the west vent, both white and pink steam. Occasionally the main vent emitted a pink cloud, but the steam from this was predominantly dark grey with ash.

A visit was made to Ngauruhoe, Red Crater (Tongariro), and Keti-tahi Springs at this time, but no abnormal activity was observed.

After 22 August, activity began to decline until the ash content of a diminished volume of steam was very slight. Landsliding of the plug material into the main vent during late August and early September increased its diameter to about 15 chains.

September: Activity was slight at the beginning of the month. Steam having a small ash content issued from the main vent with a loud roar; and a diminished volume of steam was emitted from the minor vents. Occasional explosions threw boulders out on to the ice basin. On 4 September a large volume of vapour was issuing from pits in the southern ice wall of the crater where hot boulders had fallen—probably in an explosion seen from the Chateau 15 hours previously.

Activity remained slight, and by 16 September part of the crater floor had collapsed about 10 feet. About five chains out from the crater walls a 10-foot scarp, facing the vent, extended round the plug-dome from north-east to south-east. Previously the site of this ring fault scarp had been a fissure from which steam issued. The central vent had disappeared, being incorporated in the main vent when it was enlarged. At this stage the fragmental surface of the plug-dome was a little lower than the surface of the former lake. An ice cave, the means of exit of the lake water to the Wangapehu River, was present on the south wall of the crater. Steam emission with a little ash content continued until 27 September, when activity suddenly increased. The ash-laden clouds rose to 15,000–20,000 feet in heavy bursts, with a frequency of about ten seconds. At 7.17 a.m. on 27 September, an earthquake was felt which was purely local and probably originated under the mountain. A few minutes later there was an explosion in the crater, and the eruption continued as intense continuous explosive bursts. Boulders issued from the main vent, spearing up through the ascending ash cloud and leaving black trails as if small rock particles were being expelled by expanding gas inside the hot rock. The electric discharges were most intense in these bursts. The ash cloud resembled the smoke of a violently puffing steam-engine. The vent was being cored out by these and by occasional explosions (described below in sections on explosions), which at close quarters gave a sharp crack like that of a giant rifle, but at a distance sounded more muffled. The explosions seemed to originate deep in the vent, as the resultant cauliflower of ash was already condensed and slow moving when it first appeared at the top of the vent; but in a few seconds it was more gaseous and rose at the rate of about 500 feet a second.

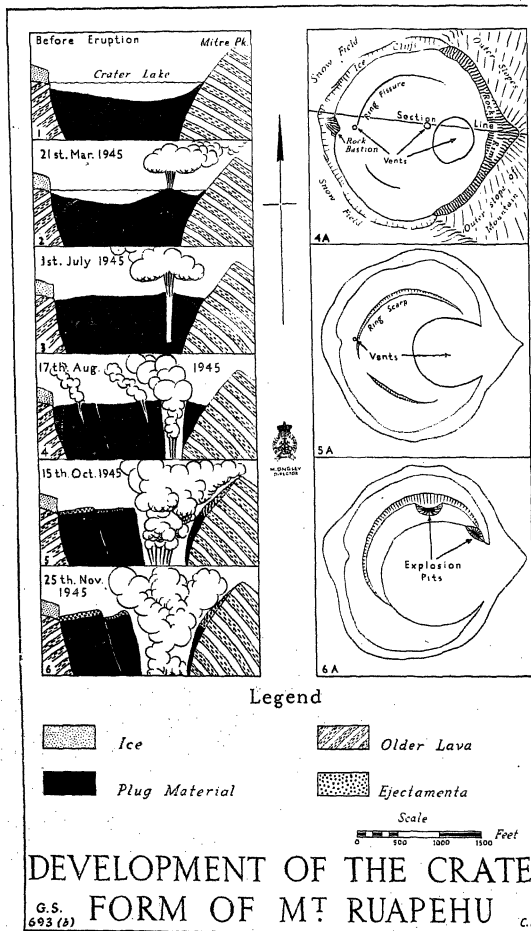


Fig. 2

Large and small boulders emerged through the cloud as spearing shafts, and rose 2,000 feet above the crater. Most of them fell back on to the plug-dome, but some whistled down on to the snowfield to embed themselves six feet or more in the ice. The steam cloud often mounted to a height of 10,000 feet above the mountain top and maintained a close white cauliflower form for up to 20 minutes. The lightning effects were very intense.

October: Activity remained very strong, but its intensity had diminished noticeably. Heavy explosions occurred at irregular intervals, and boulders three feet across were thrown as far as three-quarters of a mile from the vent on to the north-west slopes of the mountain. Small explosion pits two to three chains across were formed, one on the north-east edge of the main vent, and one on the ring fault scarp on the north side of the plug-dome (see Fig. 2 (5 and 5A)). The explosion that produced the latter pit must have projected the debris obliquely, as the western glaciers on the outer slope of the mountain were boulder-pitted one mile and a quarter from the vent, and down to the 5,000-foot level.

On 15 October, the activity had diminished further, and steam with very little ash was emitted with a loud roaring sound audible ten miles away with a favourable wind. Oblique emissions of steam from the main vent were seen from the Chateau.

Ketitahi hot-springs area was visited and a slight increase in activity was noted.

During the middle of October, explosions occurred at irregular intervals. When these occurred at night, the lightning discharges inside the ash cloud appeared reddish and gave rise to reports of flames and red-hot boulders, but could easily be distinguished from them by careful observation.

A minimum of gas emission occurred about 20 October, and then increased with the eruption of ash clouds.

November: On 3 November, the vent had been enlarged to two-fifths of the diameter of the crater (about 20 chains), and the crater itself had been enlarged southwards about six chains by the melting of the ice walls, probably by the oblique steam emissions noted during October. Since early October, the crater floor had risen 60 feet (Fig. 2 (6 and 6A)), and was within 80 feet of the crater rim, owing mainly to accumulation of ejected rocks and perhaps to an actual rise of the plug-dome. The inside of the vent showed a stratified structure of alternate layers of heavy boulders and light rubble and ash. The ring fault surrounding the central area of the crater floor had been active, for the scarp was quite distinct. The explosion pits noted previously and the plane of the ring fault were emitting much steam. The rocks thrown out from the vent were very irregular in shape and emitted opalescent blue-grey trails behind them.

About 6 November, activity reached its maximum for the whole period of eruption. Continuous ejection of rocks to 1,000 feet above the crater floor and strong steam emission from the minor explosion pits and fissures marked this maximum. Occasional heavier bursts carried rocks up to 2,000 feet, and one spectacular outburst at 8.40 p.m. on 5 November flung red-hot boulders (the only eruption of red-hot material reliably reported) 1,500 feet above the mountain top.

After this maximum the activity decreased slowly during early November. Steam with only a small ash content was erupted with a

loud roaring sound. Infrequent explosions hurled rocks one mile from the vent on to the outer glaciers.

On 17 November, after an explosion, the cloud became heavily ash laden, although the volume was less than in early November. The rate of fall of the ash was measured at this time.

By the end of November, activity was less intense, and the scarp of the ring fault had increased to from 20 to 25 feet in height. Emission of steam from the minor explosion pits and fissures was slight, and the west vent had lost its separate identity and was part of the scarp of the ring fault. The increasing collapse of the crater floor indicated that the eruption was losing force.

The writer left the area on 26 November. A later visit was made on 29 December with Mr. J. Healy, New Zealand Geological Survey. Although the view was partly obstructed by mist, the ring fault scarp was seen to have increased in height, and activity had decreased to a low-pressure emission of steam. Little steam was issuing from the scarp or from the one remaining explosion pit. The explosion pit on the edge of the main vent had disappeared, as the side of the vent had fallen in. A strip of mud had reappeared between the ice wall of the crater and the plug-dome in the north and the west quadrants.

DISCUSSION

The beginning of activity after a period of quiescence is generally held to be the culmination of a long period of building up of gas pressure beneath the plug in the conduit pipe of the volcano. When sufficient pressure has been attained, the hot gas in the reservoir breaks through and forms a new crater. This was probably the dominant mechanism in the initial stages of the 1945 eruption of Mt. Ruapehu.

L. C. Graton (1945) holds that the presence of gas reservoirs and gas fluxing is improbable, because of evidence derived from experiments giving quantitative estimates of heat losses during gas expansion. In this case, however, the mechanism suggested below does not require a gas cushion between the rising magma and the fissured plug to elevate the plug-dome, and the temperatures deduced for the upper part of a magma of hypothetical temperature and vapour content can be easily reconciled with the reheating of the plug material to between 700 and 800°C., especially as free expansion would not be permitted in a semi-enclosed system such as a fissured plug-dome without a large open vent. The absence of pumice as an eruption product means that a less gas-rich magma is involved, and hence the cooling effect would be less. (No melting of old rock is visualized in this discussion, but reheating by gas to red heat is inferred.)

That there have always been fissures in the plug filling the Ruapehu conduit pipe is suggested by the presence of and at times geyser-like ejection of mud from a warm crater lake heated by steam issuing from these fissures in its bottom. Soundings recorded in the visitors' book in the Ruapehu Ski Club's hut give the depth of the crater lake as some 200 feet some years prior to the eruption. Gas, or direct magma pressure, apparently forced the plug upwards till it appeared as an island in the lake in March, 1945. The "island" was red hot, inside a thin cool crust, owing to the heating effect of superheated steam escaping from many fissures. This "island" was closely observed by Dr. D. G. McLaughlin, of the Chateau, and was seen to rise and fall approximately 15 feet within a period of about two minutes. When it rose, the dark bouldery surface

cracked open, and these red-hot fissures emitted clouds of steam which condensed some distance above the plug-dome. When the island sank back, the fissures closed, and steam emission was much less. As the colour was a bright red, a rough estimate would put the temperature inside the crust at from 700 to 800°C.

At no time was lava seen, and molten rock must have been at least 200 to 300 feet below the surface of the plug. This phase of the eruption is described by Reed (1945) and Oliver (1945).

The gas escaping from the fissures blasted vents in the plug-dome. During July, one vent became dominant and the rise of the plug ceased, later increases being due mainly to accretions of ejected boulders.

After the period of active dome-building had ceased, the steam issuing from the vent was saturated and at low temperature, although it issued under great pressure. This suggested a deep level for the magma, which was later confirmed by a guide who ventured on to the surface of the plug-dome during a minimum of activity in October, and reported the view down the vent obscured at about 300 feet by steam clouds. During the explosive bursts, however, the gas temperature was much higher, as the debris clouds were the true colour of the rock particles—jet

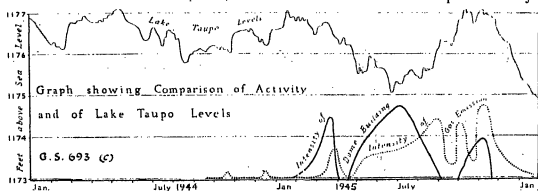


Fig. 3.—Graph by Ministry of Works.

black—and only when they had risen about a thousand feet did the steam condense and form the characteristic dark grey clouds.

With the formation of an open vent, the influence of the luni-solar tidal periodicity was apparent. The effect was small and only slightly noticeable superimposed on the major fluctuations of longer period and unknown cause.

The major rhythm began with a gradual increase in activity when the steam was heavily charged with ash. Relatively few explosions occurred, and these were very sudden. The maximum activity occurred at a luni-solar maximum, and then a gradual decline set in. Two such maxima occurred: one on 22 August, and the other on 6 November. The abrupt outbreak on 28–29 September probably had another cause.

The decline from maximum activity was marked by the internal collapse of the crater floor, forming or increasing a scarp, by many heavy explosions in the earlier part of the decline, and by the emission of steam carrying little ash. The steam issued with a loud roar markedly different from the much quieter emission during the beginning of the cycle. This was relieved infrequently by an explosion, after which, for a few hours, ash-laden steam was emitted.

After a period of decreasing activity, a slow circulation of magma below the vent must have replaced material almost exhausted of gas with magma richer in gas, and thus another major cycle was initiated.

The maximum of 28-29 September was different in that there was no slow building-up of activity from a minimum. The top of the magma column must have been almost blocked, thus preventing the circulating magma from recommencing a cycle. An earthquake, the only one during the whole of the later period of eruption and which was felt only at the Chateau, seven miles from the crater and at the base of the mountain, was probably the result of magma movements, perhaps in compensation for the loss of ash and gas, which broke up the obstruction in the vent. Soon afterwards an explosion cleared the vent completely, and the eruption proceeded at a maximum level. The decline of activity from this maximum resembled that following the August maximum.

The cycle that reached its maximum on 6 November resembled that of August, and it proved to be the maximum for the whole eruption.

The activity of the minor vents in the latter period of eruption was no doubt—in part, at least—due to the water from the melting of glaciers that formerly fed the crater lake that had become vaporized by percolating into the hot plug material.

EXPLOSIVE ACTIVITY

The most spectacular effects of the eruption were those produced by the many explosions in the crater.

There were two types of explosion cycle, for which two different explanations are suggested.

(1) During the increase of activity to maximum emission, infrequent sudden explosions occurred. The steam and ash emission would almost stop and only a small white steam cloud rise leisurely from the crater for up to two minutes. Then the gas pressure accumulated during the interval would be violently released by an explosion hurling large boulders several tons in weight as far as one mile from the vent. The sudden stoppage of steam emission before the explosion seems to indicate a sudden freezing over of the surface of the magma column, and this is borne out by the ejected boulders, which were nearly all of new vesicular lava. There were very few fragments of dark pumice. This type of explosion once blew out red-hot boulders, but never any unfrozen magma to form lapilli or bombs.

(2) These explosions occurred during the decline of activity from a maximum. For a period ranging from eight hours to several days prior to this type of explosion, the almost ash-free steam issued with a loud roar. This could be due to the steam's having to force its way through cracks and crevices in the landslides and boulders that fell from the sides of the vent after a reduction in supporting gas pressure, or a fall in magma level during the previous violent activity. The ash-free condition of the steam would thus be due to a filtering effect of the narrow and tortuous fissures. When they became too greatly blocked by ash to permit the whole volume of steam to escape, a period of little steam emission followed while the gas pressure was built up in the throat of the vent behind the obstruction. Five to ten minutes later an explosion cleared the vent for a short period, during which ash-laden steam was erupted. Then further landsliding and falling back of the ejected boulders recommenced the explosion cycle, whose length depended on the volume of steam emitted, and thus on the rate at which the vent became choked with ash. This period varied from about eight hours, when the steam was of greater volume, to several days, near a

minimum of emission, and for several days during late August had a period of 12½ hours, thus simulating regularity.

The above phase could be alternatively explained by the steam's having to force its way through a solidified vesicular plug formed by the cooling effect of the violently expanding vapour at the immediately preceding maximum, or perhaps by a combination of both processes, as definite collapse of the vent walls was evident from its increase in diameter.

If this freezing effect were dominant, the number of explosions should have decreased with decreasing steam emission. In the earlier stages of the decrease the reverse was true; but later the period of the explosive cycles decreased. When the activity began to increase again, this type of explosion should have become more frequent, but instead it became less frequent and of a different type ((1) above). The boulders thrown out included the old plug material (massive lava, which in August included blocks with a pitted reheated surface) as well as new vesicular lava.

The most likely mechanism is that of the blockage of a reduced (by solidification of part of the magma surface) surface for gas emission by the debris from internal crater collapse. This would be facilitated by a withdrawal of the magma to a greater depth in the vent.

The explosions were reported by local residents as earthquakes, since the concussion of the explosions produced the secondary effects of a quake—i.e., windows rattling, swinging doors set in motion, rumblings, etc. There was, however, only one earth tremor felt during the whole eruption, though without doubt there were many microseisms for which there were no instruments for recording until November, when the worst was over. The explosions were heard up to 30 miles from the mountain, according to the wind direction.

Electrical Effects.

Electrical effects were seen from close quarters during the maxima of eruption as short lightning discharges between the heavily ash- and boulder-laden clouds or towards the crater floor. They were accompanied by a sharp crackle like that of burning straw and were confined to the lower 500 feet or so of the cloud, where the velocity was greatest, and could not be seen from below the summit of the mountain.

The greatest effects occurred in the immense cauliflower masses formed by the heaviest explosions, and were exceedingly spectacular at night. Some seconds after the cloud was first visible, several vertical shafts would be discharged from the bottom of the column. Then vertical and horizontal discharges combined to make the whole mass of cloud a column of blue-white light for about 30 seconds, illuminating the whole top of the mountain as if by a magnesium flare, and accompanied by an intense rumble of thunder. Then the display would gradually die out, leaving the mounting cloud with only occasional reddish discharges inside it.

Rocks Involved in Eruption.

No difference in hand specimens could be seen from those described by Oliver (1945). Early in August, the ejected boulders were largely glassy and massive, with a sub-conchoidal fracture and a rough pitted surface, and were probably reheated plug material. Later, especially in November, the ejected rocks were very vesicular but of the same composition—i.e., largely glassy, with a few scattered phenocrysts.

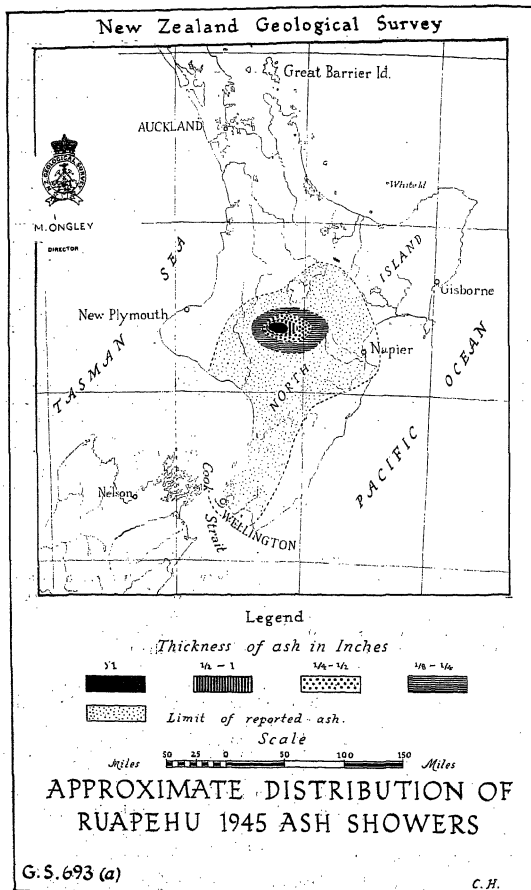


Fig. 4

Gases.

No gas samples could be collected, so that composition was inferred from the colour of the steam. As the vents could not be approached with safety, this admittedly unreliable method is the only available guide to gas compositions.

The greatest proportion of the gas was steam; and hydrogen sulphide, sulphur dioxide, and hydrogen chloride, identified by smell and sensation, were the most abundant of the other noticeable constituents.

<i>Colour of gas seen</i>		<i>Inferred constituent</i>
Pale yellow	.....	Sulphur and ferrous chloride
Pink	.....	Ferric oxide (particles)
Pale green	.....	Copper compounds, chlorine (?), and ferrous sulphate
White opalescent	.....	Sulphur
Brown	.....	Ferric chloride (?)

Ash Content of Cloud.

The ash content of the steam was variable, but one measurement was made of the amount fallen. On 17 November, ash fell at the Chateau for 14 hours, producing a layer $\frac{1}{8}$ inch thick, representing 17 tons an acre, or approximately 12,000 tons a square mile. It was difficult to estimate the area over which the ash fell, but it was approximately 25 square miles, with a thickness of $\frac{1}{8}$ inch. On the upper slopes of the mountain, ash and small gravel formed a layer up to three inches thick. The prevailing wind deposited most of the ash to the east of the mountain; and on the Desert Road between Turangi and Waiouru it formed a deposit one inch thick—i.e., 100,000 tons per square mile. Owing to variations in strength and direction of the wind, the area covered by ash is unknown, but at times it reached Napier, about 60 miles to the east, and Wanganui, a similar distance to the west. A light sprinkling of fine dust occurred in Lower Hutt district, 100 miles to the south, in August (see Fig. 4).

SUPPOSED CORRELATION WITH LAKE TAUPO LEVELS

Suggestions have been made of a possible correlation between the raising of the level of Lake Taupo in connection with the Waikato River Hydroelectric Schemes and the commencement and cessation of the eruption of Mt. Ruapehu. Lake Taupo is situated on the fault belt connecting Ruapehu with White Island, and it was suggested that the extra load imposed upon the relatively weak crust of the Taupo graben would cause isostatic sinking and displacement of magma that must be present at no great depth below the whole hydrothermal belt. It was suggested that this displaced magma would find an outlet at the weakest spot in the vicinity—viz., Ruapehu. The accompanying graphs allow the comparison of the level of Lake Taupo and the activity of Mt. Ruapehu. Dome-building activity as shown on the graph (Fig. 3) includes the building-up of debris thrown from the vent as well as actual rise of the plug-dome. During March, 1945, the plug was pushed up and appeared as an island in the lake. It sank out of sight later in March, and reappeared in mid-April and continued growing in size, reaching peak intensity at the end of June. It collapsed again in September, and during late October and early November was built up by boulder accumulation. Later in November and during December, further collapse

occurred. The intensity of gas emission has been indicated by a curve showing the relative volumes of gas emitted with minor irregularities (e.g., luni-solar maxima and minima) omitted. Both graphs are to a great extent subjective, and are relative, not quantitative. The highest point on the graph of steam emission is roughly ten times the lowest point during the active period.

In 1943, the level of Lake Taupo was raised by about four feet in connection with the Waikato River Hydroelectric Schemes. This increased load over an area of 240 square miles would not, under normal conditions, cause a shifting of isostatic equilibrium, as the crust is capable of bearing much greater stresses than this for long periods (Bucher, 31-4). However, as the bed of Lake Taupo is in part an explosion crater, and possibly a caldera depression, this weakened crust might warp under lighter loads. Sudden warping would be accompanied by local earthquakes, but there was a marked absence of seismic activity during the eruption and no extraordinary activity during the preceding year.

The level of Lake Taupo in 1944 was high and fairly uniform, and if volcanic activity at Ruapehu was caused by this there must have been a long period of lag, as the eruption began when the lake level was falling, in March, 1945. The period of maximum dome-building and steam emission occurred when the lake was at its lowest level for two years, and activity became less when the lake level rose again in September, 1945. A maximum of steam emission and dome-building occurred in November at a period of maximum lake level, and the lake level and activity declined together in December, 1945.

Little correlative agreement in the graphs can be seen except for the November maximum and the December decline. Once the magma had overcome the initial resistance of the plug in the crater—i.e., in March, 1945—the activity should roughly reflect the broad pattern of maxima and minima of lake level, perhaps with some time lag, if such a correlation is justified. As the graph shows, there is little to support the suggested correlation, and the evidence seems to show the independence of volcanic activity and lake level.

CONCLUSION

The activity of Mt. Ruapehu resembles that of Perrett's Open Cone type of dome, and he considers that this type of activity denotes waning eruptive force, and this seems justified with regard to Mt. Ruapehu.

It is the writer's view that the 1945 eruption was less severe than that at the time of the legendary battle of the mountains of Maori folklore in which Ruapehu took part. That eruption left a crater occupied by the former crater lake. The vent of the present eruption occupies a small area of that crater. Probably no lava flowed from Ruapehu during the former eruption, as the latest lava flows on its flanks are ice plucked and must have occurred long before Maori times. If this hypothesis of waning activity is correct, the period of quiescence following the present eruption is likely to be longer than that preceding it to the 1945 eruption, and any subsequent activity less severe.

ACKNOWLEDGEMENTS

Acknowledgement is made to the Mental Hospitals Division of the Department of Health for providing accommodation and making avail-

able the facilities of the Chateau; to Mr. A. Manson for his services as guide; and to various tramping clubs for their help.

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TOXICITY OF WATER-SOLUBLE WOOD-PRESERVATIVES TO WOOD-DESTROYING FUNGI

By K. M. HARROW, Plant Diseases Division, Department of Scientific and Industrial Research, Auckland.

Summary

The toxicity of four water-soluble materials to wood-destroying fungi was tested by the wood-soil contact culture method of Leutritz. Tests were made with *Pinus radiata* blocks using the following test fungi: *Coniophora cerebella* (two cultures), *Lenzites trabea*, and *Poria vaporaria*.

Loadings of salt in the blocks were expressed as the percentage of dry salt in oven-dry wood, w/w. A toxicity index expressing the loss in weight of the treated block relative to the loss in weight of the untreated block from the same jar was calculated, the index being 100 when treated blocks were unrotted, and 0 when losses in weight of treated and untreated blocks were equal.

INTRODUCTION

Compared with insect attack, fungous decay of timber is a minor problem in New Zealand buildings, being associated with faulty design or neglect. However, for some purposes, building timber might with advantage be impregnated with preservatives at loadings which are toxic to fungi as well as to insects. Toxicity of a number of materials to the common house borer (*Anobium punctatum* de Geer) have been reported by Spiller (1948a, 1948b, 1948c, 1948d). Four of the most promising of these—i.e., boric acid, sodium fluoride, tanalith, and zinc chloride—have now been tested for toxicity to wood-destroying fungi, using the wood-soil contact culture technique of Leutritz (1946).

Published data on toxicity of these materials to wood-destroying fungi as determined by any wood-block method are meagre. Richards and Addoms (1947) showed that the toxicity of zinc chloride measured by an agar-block method was greater than when measured by a soil-block method. *Lenzites trabea*, the only fungus common to the tests of Richards and Addoms and that described in this paper, was reported to cause less than 5 per cent. loss in weight of blocks at a retention of 0.25 pound of zinc chloride per cubic foot in a soil-block test and no loss in an agar-block test.

Cartwright and Finlay (1946) gave results of a test of the toxicity of commercial sodium fluoride against *Coniophora cerebella* using the agar-block method, the toxic limit being between 0.3 and 0.4 kilograms per cubic metre.

Leutritz's method was chosen in preference to the British Standard (Anon., 1939) wood-agar technique in kolle flasks. With the Leutritz technique, test blocks can be maintained at about fibre saturation point, thus virtually eliminating leaching; with the kolle flask method, blocks frequently became very wet. In addition, there is evidence that rotting is more severe with the soil-block method than with the agar-block method.

In the test, it was desired to use fungi found in New Zealand buildings. However, the commonest of these, *Fuscoporia contigua* (Pers. ex Fr.) G. H. Cunn., could not be used as it would not grow on soil



FIG. 1.—A group of jars at the end of the test period.

culture, and a species of *Stercum* occasionally found in buildings was also unsuitable as it caused only four per cent. loss in weight of untreated blocks in two months.

The fungi used in the test were as follows:—

Coniophora cerebella (N.Z. isolation—No. 81).

C. cerebella (ex Forest Products Laboratory, Princes Risborough).

Poria vaporaria (Liese's Strain ex Forest Products Laboratory, Princes Risborough).

Lenzites trabeca (Madison 617. Division of Forest Products, Madison).

Using these four cultures, a test was set up with each of the four materials previously mentioned, at four loadings, each replicated four times. A total of 256 jars, each containing one water-treated block and one salt-treated block was thus required.

EXPERIMENTAL

Treatment of Blocks

Pinus radiata wood blocks $1\frac{1}{2}$ in. $\times$ $15/16$ in. $\times$ $\frac{7}{8}$ in. ($\frac{7}{8}$ in. along grain) were accurately cut to size with a hollow-ground circular saw and the rough edges cleaned with sand-paper. After oven-drying at 105°C ., only those which fell into the commonest weight group—viz., 7.7 to 8.5 grams—were selected for treatment. Prior to treatment, blocks were again oven-dried, numbered, and stacked in a dry two-litre beaker and weighted to prevent their floating when treated. The beaker was placed in a desiccator attached to a "Hyvac" pump and manometer. The desiccator was exhausted of air until the pressure was less than 2 mm. Hg., and sufficient solution to cover the blocks adequately was then run rapidly into the beaker. The vacuum was released and blocks

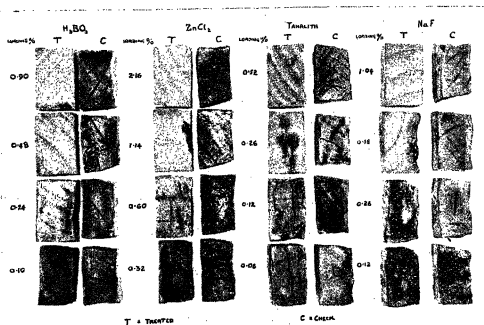


FIG. 2.—One treated block and its associated check block from each treatment of the series exposed to *Coniophora cerebella*.

left submerged for 30 minutes, after which treatment they were wiped, weighed, and held on wire trays in a room until air dry. The weight of solution absorbed by each block was expressed as a percentage of the oven-dry weight of the block and designated absorption percentage. Water check blocks were treated first, and from their absorption percentages the solution concentration required to give the desired salt loading was determined. A sample of each solution used was held for analysis and the loading of each block was calculated from the solution analysis and absorption percentage. The initial selection of blocks by weight reduced variation in the specific gravity, with the result that the absorption percentage of the treated blocks was fairly constant. From each treatment of 24 blocks, it was possible to select 16 which fell within the absorption range of 195 to 205 per cent. That the method of treatment used resulted in complete saturation of the blocks was shown by comparison of weighed absorption with potential maximum absorption

TABLE I. LOSS IN WEIGHT OF *PINUS RADIATA* BLOCKS IN 12 WEEKS
IN TEST AGAINST *C. CEREBELLA* (PRINCES RISEBOROUGH). MEANS OF
FOUR REPLICATIONS.

	Boric acid			Zinc chloride		
	%	%	%	%	%	%
Loading % oven dry weight	0.51	0.26	0.14	1.0	0.77	0.40
Treated	0.4	1.6	19.8	0	0.4	11.4
Check	37.1	38.1	34.4	38.4	37.8	37.3

Loss in weight calculated from $100 - \left(\frac{\text{rotted oven dry weight}}{\text{oven dry weight}} \times 100 \right)$

based on void volume of blocks. For example, a block with an oven-dry weight of 8.1 grams and a wet volume of 21.4 cubic centimetres had an absorption of 16.2 grams of solution. The calculated void volume of the block was 16.1 cubic centimetres.

Loadings Used in Test

In a preliminary test of Leutritz technique, boric acid and zinc chloride were used as preservatives with *C. cerebella* (Princes Risborough) as test fungus. From the results (Table I), it was possible to select a range of loadings which included the toxic point. The range of loadings used with tanalith and with sodium fluoride was selected by estimation of probable performance.

The mean loadings in the blocks (percentage of dry salt in oven-dry wood, w/w), the solution concentrations used, and the retentions in kilograms per cubic metre (calculated from the air-dry block volume of 19.56 cubic centimetres, a mean solution absorption of 16.1 grams, and solution concentrations) are listed below.

Salt	Loading per cent.	Solution concen- tration per cent.	Retention kg. per m. ³
Boric acid	0.90	0.45	3.7
	0.48	0.24	2.0
	0.24	0.12	1.0
	0.10	0.05	0.4
Sodium fluoride	1.04	0.52	4.3
	0.51	0.26	2.1
	0.26	0.13	1.1
	0.12	0.06	0.5
Tanalith	0.52	0.26	2.1
	0.26	0.13	1.1
	0.12	0.06	0.5
	0.06	0.03	0.2
Zinc chloride	2.16	1.08	8.9
	1.14	0.57	4.7
	0.60	0.30	2.5
	0.32	0.16	1.3

NOTE.—1 kg. per m.³ = 0.06 lb. per ft.³

The solution concentrations of tanalith were based on analyses of both sodium arsenate and sodium chromate.

Preparation of Cultures

Approximately 100 grams of sieved volcanic top soil (moisture content 28 per cent.) was lightly pressed into 1-pound jam-jars fitted with metal screw caps. Two strips of pine, 1½ in. x 1 in. x 3/16 in., were placed slightly apart on top of the soil to provide bases for test blocks. With lids lightly screwed down, jars were autoclaved at 12½ pounds per square inch pressure for one hour.

When cool, the jars were inoculated and then held in a room at 23 ± 1°C. Cultures were grown for four weeks before test blocks were introduced into jars. All cultures grew well. *P. vaporaria* did not grow into the soil but formed a thick mat of mycelium on the surface. Blocks of each treatment were placed in a paper bag and autoclaved for 30 minutes. When cool, one water-check block and one treated block were placed on the strips in each jar. Lids were screwed down tightly and jars were returned to the temperature-controlled room at 23°C.

TABLE II. LOSS IN WEIGHT OF PAPER RADIAN TEST BLOCKS IN 14 WEEKS
(MEANS OF FOUR REPLICATIONS)

Salt	Loading % O.D. WT.	<i>D. cerebella</i> New Zealand		<i>C. cerebella</i> Princes Risborough		<i>P. versiparis</i> Princes Risborough		<i>Penicillium</i> Madison	
		% Treated	% Check	% Treated	% Check	% Treated	% Check	% Treated	% Check
Sulphuric acid	0.90	0	26.9	0	40.3	0	16.3	0	18.5
	.48	3.4	29.2	0.7	33.8	0	16.4	0.6	18.2
	.24	7.5	25.7	8.8	37.6	0.7	17.9	5.0	14.4
	.10	26.3	24.6	31.5	37.5	8.6	15.5	14.6	19.1
Sodium fluoride	1.04	0.3	45.0	0	50.0	0	19.0	0	23.8
	0.51	23.7	33.8	12.7	43.7	8.1	20.9	8.6	26.2
	0.26	41.8	43.9	30.5	44.5	12.4	20.7	17.9	30.4
	0.12	39.0	39.0	42.7	47.7	12.9	13.7	28.6	31.7
Zinc sulphate	0.52	2.6	32.4	6.1	47.8	0	17.3	5.2	25.8
	0.26	4.7	36.8	15.8	49.5	0.5	19.4	25.1	28.0
	0.12	28.6	36.7	24.6	45.7	6.5	24.4	29.0	28.3
	0.06	58.2	39.9	41.1	44.2	6.3	18.8	23.7	27.6
Zinc chloride	2.16	0	27.9	0	37.3	1.4	11.3	0	10.3
	1.14	1.4	24.4	1.0	36.7	8.3	10.6	2.0	14.4
	0.60	10.9	26.1	16.6	41.4	6.8	11.8	4.5	16.1
	0.32	19.1	20.8	24.0	30.7	8.9	15.6	10.9	25.6

TABLE III. TOXICITY INDICES OF SALTS TESTED
(CLASS OF FOUR REPLICATIONS)

Salt	Loading % O.D. WT.	<i>D. cerebella</i> New Zealand	<i>C. cerebella</i> Princes Risborough	<i>P. versiparis</i>	<i>P. griseus</i>	Treatment Mean
Sulphuric acid	0.90	100	100	100	100	100
	0.48	91.2	98.4	100	97.0	96.6
	0.24	67.2	76.6	90.7	64.4	74.7
	0.10	-9.6	13.4	29.2	17.2	15.0
Sodium fluoride	1.04	99.4	100	100	100	99.8
	0.51	27.7	67.8	69.5	64.5	55.6
	0.26	4.3	31.4	16.3	41.6	23.4
	0.12	-1.0	10.6	-0.6	12.1	5.3
Zinc sulphate	0.52	91.9	86.4	100	77.7	89.0
	0.26	85.6	60.2	97.2	30.7	68.3
	0.12	25.6	46.9	75.3	11.0	39.7
	0.06	-9.5	6.9	69.7	15.6	20.6
Zinc chloride	2.16	100	100	89.5	100	97.4
	1.14	94.5	97.0	80.5	96.2	74.5
	0.60	56.4	60.6	38.3	77.4	58.2
	0.32	6.6	17.5	45.2	57.1	31.7
Difference for significance between any two means						10.2
						13.4

After 14 weeks, blocks were removed, lightly brushed free of adhering mycelium, weighed, oven-dried, and reweighed. Fig. 1 shows a group of jars at the end of the test period.

RESULTS

The results of the test are shown as loss in weight percentages in Table II and as toxicity indices in Table III. The index was calculated from the following formula:—

$$100 \frac{\% \text{ loss in weight of check block} - \% \text{ loss in weight of treated block}}{\% \text{ loss in weight of check block}}$$

In Fig. 2 are shown one treated block and its associated check block from each treatment of the series exposed to *C. cerebella* (Princes Risborough). The mean moisture contents of unrotted treated blocks are shown in Table IV.

DISCUSSION

Examination of mean weight loss of check blocks (Table II) shows that the different fungi caused different degrees of rotting. It is of interest to note also that, with all fungi, the losses in weight in check

TABLE IV. MEAN MOISTURE CONTENT %
OF UNROTTED BLOCKS AT END OF TEST

Salt	Boric acid		Sodium fluoride	Tanalith	Zinc chloride	
Loading %	0.90	0.48	1.04	0.52	2.16	1.14
% Moisture content	30.3±1.1	28.6±0.1	49.5±4.8	30.9±1.4	49.0±4.2	40.0±3.1
No. of blocks	16	10	15	7	15	7

blocks of the sodium fluoride and tanalith series were greater than in check blocks of the boric acid and zinc chloride series. Blocks with lowest loadings of sodium fluoride and tanalith were also more severely rotted.

The toxicity index in Table III corrects for variation in decay between jars, and is a better basis for comparison of treatments than loss in weight percentages of treated blocks. The index removes differences in rotting potential, but not differences due to resistance of different fungi to preservation, such as shown by *P. vaporaria* to zinc chloride, and *L. trabea* to tanalith.

It is unfortunate that the range of loadings chosen for tanalith was too low to include the toxic limit. With the top loadings of both sodium fluoride and zinc chloride, only one block in each case was attacked.

The results indicate that with the fungi and culture technique used, the toxic loading of boric acid is between 0.5 and 0.9 per cent., of sodium fluoride about 1.04 per cent., of tanalith more than 0.52 per cent., and of zinc chloride about 2.16 per cent.

For preservation of building timbers where the leaching hazard should be negligible, results of toxicity tests, together with information on the distribution and net absorption of preservative obtained by different treating methods, can be used directly as a basis for recommended treatments.

The data in Table IV show the effect of salt treatment on the moisture content of blocks. It is not known whether these differences in moisture content affect the response by fungi to preservatives.

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THE MOLLUSCAN FAUNA OF THE FIORDS OF WESTERN SOUTHLAND

(A Report of the *New Golden Hind* Expedition, 1946)

By C. A. FLEMING, New Zealand Geological Survey, Department of Scientific and Industrial Research, Wellington.

Summary

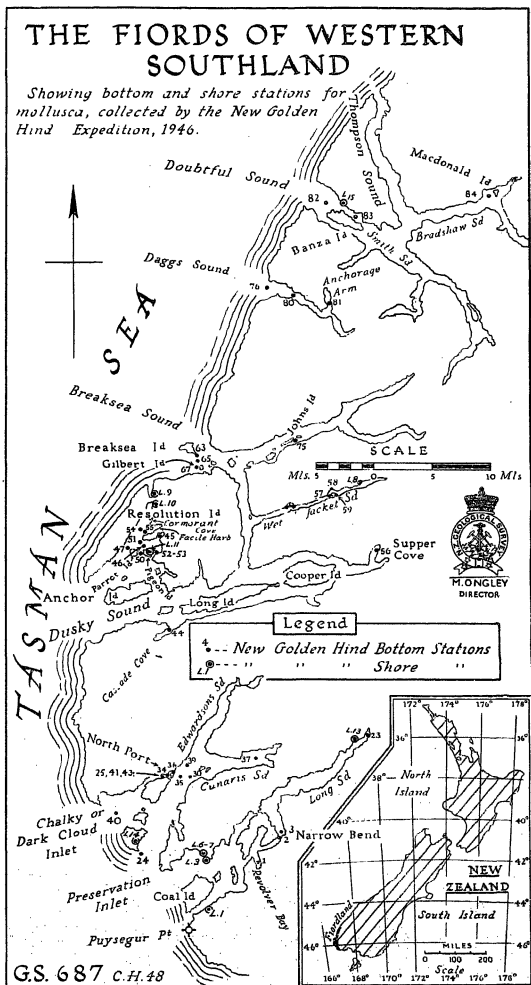
A check-list of the marine shelled mollusca of the Fiords of Western Southland based on collections of the *New Golden Hind* Expedition (1946) comprises 342 species, many of which have not previously been recorded from the area. Ecological factors, bottom communities, and the affinities of this molluscan fauna are briefly discussed.

INTRODUCTION

During the course of the expedition of the Department of Scientific and Industrial Research to the fiords of Western Southland in February, 1946, 84 bottom samples were collected, mainly by Mr. H. W. Wellman (of the Geological Survey) and Mr. C. S. Wright (of the Soil Research Bureau). The samples were obtained from depths of 2 to 73 fathoms with a small Petersen grab, the property of the Fishery Research Laboratory of the Marine Department, operated by hand from the ship's dinghy. The samples came from Preservation Inlet, Chalky Sound, Dusky Sound, Breaksea Sound, Daggs Sound, and Doubtful Sound, and their various branches. The *New Golden Hind* did not visit more northerly sounds in 1946, but an additional sample, obtained from 34 fathoms at the entrance to George Sound from the New Zealand Government steamer *Matai* in 1935, has been made available by Dr. P. Marshall. Members of the *New Golden Hind* party made a number of beach and littoral collections of mollusca which are also considered in this paper, but the dredged material has provided the bulk of the species on the faunal list.

In the *Manual of New Zealand Mollusca* (1913), H. Suter recorded some 56 species of mollusca from the southern fiords, and of these six were originally described from that area. The mollusca from two samples dredged from 100 fathoms and 170 fathoms off Puysegur Point, collected by a private scientific party which visited the sounds in the *Rakiura* in December, 1908, were described by Powell (1927): 97 species were listed, 22 of them new to science, and all but 10 of them additional to those recorded by Suter. Since then Powell has added six further new species described from the sounds (1935, 1939, 1946a). From the coast of the south-west portion of the South Island, an area defined for convenience as extending from Puysegur Point in the south to Milford Sound in the north, some 150 species have hitherto been recorded. The *New Golden Hind* material enables presentation of a list of 342 species of mollusca from this region, which may conveniently be referred to as "Fiordland."

Of the 84 *New Golden Hind* bottom samples, only 40 have so far been examined in detail for mollusca, so that additional records are to be expected. Nevertheless, the samples examined fairly represent the range of localities and depths covered by the complete series, and the accompanying check-list is offered as a basis for future additions, and to allow of tentative analysis of the nature of the molluscan fauna of



Fiordland. Some systematic topics arising from examination of the collections have been published elsewhere (Fleming, 1948).

In the check-list, the nomenclature follows, in general, that of Powell's *Check-list of New Zealand Mollusca* (*Shellfish of New Zealand*, 2nd ed., 1946b, pp. 55-100): comment on some minor variations will be found in a previous paper (Fleming, 1948). *Pecten novaezelandiae*, *Hunkydora a. novaezelandica* (= *transenna*), and *Micrelenchus caelatus* (= *sanguineus* of authors) are the subjects of nomenclatural notes in a paper, "Some Australasian Mollusca in the British Museum, Natural History," submitted to the *Trans.Roy.Soc.N.Z.* One point may be noted: where a polytypic species—i.e., one in which subspecies have been described—is listed binomially, this implies that the subspecies has not been determined, and not that the nominate subspecies is identified.

CHECK-LIST OF THE MOLLUSCA OF FIORDLAND

PELECYPODA:

- Solemya* (*Zesolemya*) *parkinsoni* E. A. Smith, 1874 (S, N.G.H. 57).
Nucula hurteigiana Pfeiffer, 1864 (S,P, N.G.H. 3, 25, 44, 51, 54, 55, 58, 75).
Nucula nitidula A. Ad., 1856 (G, N.G.H. 34, 35, 37, 40, 41, 43, 53, 63, 67, 75).
Nucula castanea A. Ad., 1856 (S, N.G.H. 80).
Nucula dunedinensis Finlay, 1928 (N.G.H. 24, 80).
Nucula aff.gallinacea Finlay, 1928 (N.G.H. 39, 46, 52, 80, 82).
Pronucula tenuis Powell, 1927 (P,G, N.G.H. 34, 81).
Nuculana (*Sacella*) *bellula* (A. Ad., 1856) (S, N.G.H. 25, 34, 35, 37, 44, 45, 46, 49, 51, 52, 54, 55, 65, 80, 81, 82, 83).
"Orvula" *hamiltoni* (Powell, 1935) (N.G.H. 37, 39, 46, 52, 80, 81, 82).
Nucinella maoriana (Hedley, 1904) (S,G, N.G.H. 1, 2, 3, 39, 41, 46, 51, 52, 58, 75, 80, 81, 82, 83).
Poroleda lanecolata (Hutton, 1885) (S, N.G.H. 52).
Ncilo australis (Q. & G., 1835) (N.G.H. 1, 23, 25, 44, 45, 84).
Austrotindaria wrighti Fleming, 1948 (N.G.H. 39, 52).
Monia zelandica (Gray, 1843) (S,P,G, N.G.H. 2, 3, 35, 37, 39, 40, 50, 57, 58, 63, 75, 81, 83).
Batharca cybaca (Hedley, 1906) (N.G.H. 3, 37, 39, 46, 51, 81, 82).
Arca novaezelandiae Smith, 1915 (N.G.H. 39, 49, 50, 57, 58, 63, 67, 75, 80, 82, 83).
Grandaxinea laticostata (Q. and G., 1835) (N.G.H. 54, 58, 67).
Glycymerula modesta (Angas, 1879) (G, N.G.H. 24, 35, 49, L,2, 6).
Lissarca stationis Fleming, 1948 (N.G.H. 81).
Austrosarcia trapezina (Bernard, 1897) (P, N.G.H. 76, 80, 81).
Austrosarcia harrisonae (Powell, 1927) (P, G, N.G.H. 2, 24, 34, 40, 63, 65, 67, 76, 80, 81, 82, 83).
Hochstetteria mclayrini Bernard, 1896 (P,G, N.G.H. 2, 63, 80).
Hochstetteria modiolus (Suter, 1913) G, N.G.H. 2, 24, 67, 76, 80, 82, 83).
Cosa costata (Bernard, 1896) (P,G, N.G.H. 2, 25, 40, 63, 67, 75, 80, 82, 83).
Cosa filholi (Bernard, 1897) (G, N.G.H. 2, 63, 67, 80, 81, 82).
Perrierina taxodonta Bernard, 1897 (G).
Perrierina perstriata Fleming, 1948 (N.G.H. 65, 80).
Perrierina georgiana Fleming, 1948 (G, N.G.H. 2, N.G.H. 40, 65).

- Perrierina mairi* Fleming, 1948 (G, N.G.H. 76).
Cyamiomactra problematica Bernard, 1897 (P.G. N.G.H. 2, 24, 40, 54, 80).
Mytilus planulatus Lam., 1819 (N.G.H. 2, 13).
Aulacomia maoriana (Iredale, 1915) (N.G.H. 2, 50, 57, 63, 80, L. 3, 9, 15).
Modiolus aerolatus (Gould, 1850) (N.G.H. 57).
Modiolus neozelanicus (Iredale, 1915) (N.G.H. 57, 80).
Modiolaria impacta (Hermann, 1782) (N.G.H. 57, L. 12).
Trichomusculus barbatus (Reeve, 1858) (N.G.H. 40, 67).
Dacrydium pelseneri Hedley, 1906 (P).
Pecten novaezelandiae new subspecies (N.G.H. 25, 43, 50, 53, 56, 67, L. 1, 8).
Chlamys radiata (Hutton, 1873) (S, N.G.H. 2, 3, 25, 35, 37, 39, 45, 46, 57, 83).
Chlamys suprasilis crepusculi Fleming, 1948 (N.G.H. 45, 49, 57, 58).
Chlamys celator Finlay, 1928 (N.G.H. 49).
Pallium (Mesopeplum) convexum (Q. and G., 1835) (S, N.G.H. 2, 25, 49, 50).
Cyclopecten (Cyclochlamys) transennus (Suter, 1913) (G, N.G.H. 40, 46, 67, 76, 80, 81).
Cyclopecten (Cyclochlamys) cf. aupouria Powell, 1937 (N.G.H. 80).
Cyclopecten (Cyclochlamys) cf. secundus Finlay, 1926 (N.G.H. 46).
Lima zelandica Sowerby, 1876 (S, N.G.H. 49, 57, 58, 59, 65, 75).
Limatula maoria Finlay, 1926 (P.G, N.G.H. 2, 3, 25, 35, 39, 46, 49, 55, 75, 80, 81, 83).
Limatula suteri (Dall, 1908) (N.G.H. 3, 67).
Promantellum murrayi (E. A. Smith, 1891) (P).
Kidderia marshalli Fleming, 1948 (G).
Kidderia aupouria fiordlandica Fleming, 1948 (G, N.G.H. 40, 65).
Costokidderia costata (Odhner, 1924) (N.G.H. 2, 24, 80, 81, 83).
Costokidderia n.sp. (G, N.G.H. 65, 82).
Cuna laqueus Finlay, 1926 (S.P, N.G.H. 67).
Cuna carditelloides Suter, 1907 (N.G.H. 51, 82).
Hamacuna ottagensis (Powell, 1927) (P).
Hamacuna gibbosa (Powell, 1937) (N.G.H. 54).
Cardita aotana Finlay, 1926 (N.G.H. 2, 3, 24, 25, 34, 36, 39, 40, 41, 49, 50, 57, 58, 63, 67, 75, 82, L. 6, 7).
Venericardia purpurata (Desh., 1854) (P, N.G.H. 2, 45, 49, 53, 57).
Pleuromeris zelandica (Desh., 1854) (N.G.H. 3, 25, 35, 36, 37, 39, 44, 45, 46, 52, 54, 55, 57, 58, 65, 75, 82, 83, 84).
Pleuromeris marshalli Marwick, 1924 (P, N.G.H. 3, 34, 36, 39).
Ferticopronus mytilus Hedley, 1904 (G, N.G.H. 2, 24, 40, 53, 67, 76, 80, 82, 83, L. 7).
Condylocardia concentrica Bernard, 1897 (P, N.G.H. 81).
Condylocardia crassicosta Bernard, 1896 (P, N.G.H. 37, 53).
Condylocardia pectinata chathamensis Powell, 1933 (G).
Dicentricella cumingi (Ad. and Ang., 1863) (N.G.H. 23, 25, 34, 35, 37, 44, 45, 52, 53, 54, 56, 57, 58, 67, 80, 83, 84, L. 2).
Taras (Zemysia) zelandica (Gray, 1835) (G, N.G.H. 35, 54, 67).
Taras (Zemysia) globus Finlay, 1926 (N.G.H. 25, 41).
Thyasira peroniana peregrina Iredale, 1930 (S, N.G.H. 25, 34, 41, 43, 44, 45, 50, 52, 57, 58, 80).

- Maorithyas marama* Fleming, 1950 (N.G.H. 1, 25, 34, 41, 45, 50, 52, 53, 75, 80).
- Genaxinus otagoensis* (Suter, 1913) (S, N.G.H. 3, 37, 54, 57, 67).
- Lasaea rossiana tutunekai* Fleming, 1948 (G, N.G.H. 2, 41, 59, 63, 67, 75, 80, 83, L. 7).
- Lasaea hinemoa* Finlay, 1928 (N.G.H. 24, 53).
- Pachybellia edwardsi* Bernard, 1897 (P).
- Pachybellia concentrica* Powell, 1927 (P).
- Pachybellia bernardi* Powell, 1927 (P).
- Pachybellia rotunda* Powell, 1927 (P).
- Puysseguria cuneata* Powell, 1927 (P, N.G.H. 76).
- Puysseguria prognata* Powell, 1927 (P, N.G.H. 76).
- Melliteryx parva* (Desh., 1856) (S.P.G, N.G.H. 3, 24, 34, 39, 40, 41, 44, 46, 51, 52, 58, 67, 80, 82, 83).
- Mysella hauri* Fleming, 1948 (N.G.H. 34).
- Mysella unidentata* (Odhnner, 1924) (P, G, N.G.H. 2, 24, 34, 35, 39, 81).
- Rocheportula reniformis* (Suter, 1908) (S, G, N.G.H. 2, 34, 39, 80).
- Rocheportula decapitata* Powell, 1939 (G, N.G.H. 2, 35, 54, 80).
- Rocheportula taiariensis* Powell, 1939 (N.G.H. 2).
- Notolepton antipodum* (Filhol, 1880) (N.G.H. 2, 45, 46, 63, 75, 76, 80, 82, 83).
- Notolepton sanguineum* (Hutton, 1883) (P,G, N.G.H. 35, 58, 65, 67, 81).
- Scintillona zelandica* (Odhnner, 1924) (N.G.H. 37, 41, 43, 45).
- Tellinella eugonia* (Suter, 1913) (N.G.H. 45, 80).
- Macomona lilliana* (Iredale, 1915) (N.G.H. 56, L. 9).
- Angulus (Peronidea) edgari* (Iredale, 1915) (N.G.H. 25, 54).
- "*Tellina*" *huttoni* (E. A. Smith, 1885) (S, N.G.H. 23, 25, 44, 45, 46, 50, 52, 54, 56, 84).
- Zearcopagia disculus* (Desh., 1855) (N.G.H. 53, L. 4, 11).
- Leptomysa retiaria* (Hutton, 1885) (N.G.H. 23, 25, 34, 41, 43, 45, 57, 82).
- Amphidesma (Taria) forsteriana* Finlay, 1926 (L. 6).
- Amphidesma (Paphies) australe* (Gmelin, 1791) (N.G.H. 1, 3, 23, 56, L. 2, 4, 13).
- Mactra discors* Gray, 1837 (S. L. 10).
- Longimactra elongata* (Q. and G., 1835) (N.G.H. 2, L. 1).
- Scalpomactra scalpellum* (Reeve, 1854) (P,G, N.G.H. 24, 35, 40, 46, 51, 52, 54, 55, 65, 67, 76, 84).
- Dosinia (Kercia) grayi* Zittel, 1864 (N.G.H. 25, 44, 45, 84).
- Notocalista multistriata multistriata* (Sowerby, 1851) (S, N.G.H. 3, 25, 44, 45, 46, 49, 52, 54, 55, 58, 65, 75, 84).
- Dosinula zelandica* (Gray, 1835) (N.G.H. 25, 49).
- Tawera spissa* (Desh., 1835) (S.P, N.G.H. 3, 23, 24, 25, 34, 35, 36, 39, 41, 43, 44, 45, 49, 52, 53, 54, 56, 57, 58, 63, 67, 75, L. 2, 3, 4).
- Chione (Austrovenus) stutchburyi* (Gray, 1828) (N.G.H. 23, 44, 56, L. 9, 10, 13).
- Protothaca (Tuangia) crassicauda* (Desh., 1835) (L. 2, 9, 10).
- Paphirus largillierii* (Philippi, 1849) (N.G.H. 82, L. 2, 4).
- Notirus reflexus* (Gray, 1843) (N.G.H. 39).
- Nemocardium pulchellum* (Gray, 1843) (S, N.G.H. 1, 2, 3, 25, 34, 35, 37, 39, 45, 46, 49, 52, 55, 80, 82).
- Gari stangeri* (Gray, 1843) (N.G.H. 2, 34, 53, 63, 80, L. 4, 12).

- Gari lincolata* (Gray, 1835) (N.G.H. 54, L. 1, 2).
Ascitellina urinatoria (Suter, 1913) (P.G. N.G.H. 24, 40, 55, 63, 67).
Soletellina siliqua Reeve, 1857 (S).
Notocorbula (*Anisocorbula*) *zelandica* (Q. and G., 1835) (S, N.G.H. 3).
Hiatella australis (Lam., 1818) (G, N.G.H. 2, 23, 24, 35, 39, 40, 65, 67, 80, 81).
Eximiothracia vitrea (Hutton, 1873) (N.G.H. 2, 3, 24, 25, 84).
Parvithracia suteri Finlay, 1927 (N.G.H. 35, 46, 81, 82, 83).
Myadora antipodum (E. A. Smith, 1880) (S, N.G.H. 2, 3, 25, 34, 37, 49, 50, 52, 54, 55, 63, 80).
Myadora biconvexa Powell, 1927 (P).
Myadora striata (Q. and G., 1835) (N.G.H. 45, L. 2, 6).
Myadora subrostrata E. A. Smith, 1880 (G, N.G.H. 35, 39, 46, 63, 65, 75, 80, 82).
Hunkydora australica novozelandica (Reeve, 1859) (N.G.H. 45, 67).
Habiris (*Setaliris*) *setosa* (Hedley, 1907) (N.G.H. 3, 81).
Cuspidaria fairchildi Suter, 1908 (N.G.H. 80).
Cuspidaria trailli (Hutton, 1873) (S.P, N.G.H. 45).
Cuspidaria willetti Fleming, 1948 (N.G.H. 25).
Austroneacra n.sp. (N.G.H. 49).
Austroneacra wellmani Fleming, 1948 (N.G.H. 34, 44).

GASTEROPODA:

- Scissurella stellae* Fleming, 1948 (N.G.H. 34, 41, 53).
Schizotrochus regius (Mestayer, 1926) (N.G.H. 2, 3, 35, 39, 49, 75, 80, 81, 83).
Schizotrochus mantelli (Woodward, 1859) (P, N.G.H. 2, 80).
Scissurona rosea (Hedley, 1904) (N.G.H. 39, 41, 80, 81).
Sinezona laevigata (Iredale, 1908) (G, N.G.H. 2, 76, 82).
Schismope iota Finlay, 1926 (P).
Schismope laqueus Finlay, 1926 (P.G.).
Schismope lyallensis Finlay, 1926 (P.G. N.G.H. 39).
Haliotis iris Martyn, 1784 (L. 4).
Haliotis australis Gmelin, 1790 (L. 4).
Haliotis virginea virginea Gmelin, 1790 (N.G.H. 63, L. 4).
Incisura lytteltonensis (Smith, 1894) (G, N.G.H. 34, 80, 81).
Emarginula striatula (Q. and G., 1834) (P, N.G.H. 25, 37, 43, 49, 57, 58, 75, 80, 81, 82).
Tugali suteri sutherlandi Fleming, 1948 (N.G.H. 41, 63).
Puncturella (*Facerra*) *demissa* (Hedley, 1904) (P, N.G.H. 36, 80).
Monodilepas monilifera (Hutton, 1873) (P).
Coelotrochus tiarutus (Q. and G., 1834) (N.G.H. 34, 39, 41, 43, 45, 53, 56).
Thorista viridis (Gmelin, 1791) (N.G.H. 34, 36, 41, 43, 53, 57, 58, 67, L. 3, 4, 12).
Thoristella chathamensis benthicola Finlay, 1926 (N.G.H. 34, 45, 53, 57, 63).
Thoristella chathamensis chathamensis (Hutton, 1873) (S, N.G.H. 39).
Melagraphia aethiops (Gmelin, 1791) (N.G.H. 34, L. 6, L. 7, 10, 12, 15).
Zediloma arida Finlay, 1926 (S, L. 1, 6, 7).

- Zediloma digna* Finlay, 1926 (L. 9).
Zediloma (Fractarmilla) corrosa zebrina Powell, 1946 (N.G.H. 84, L. 7, L. 10, 13).
Zediloma (Fractarmilla) atrovirens (Philippi, 1851) (L. 15).
Zediloma (Fractarmilla) morio (Troschel, 1851) (S).
Cavodiloma coracina (Philippi, 1851) (L. 7).
Anisodiloma lugubris lenior Finlay, 1926 (L. 1, 7, 15).
Cantharidus opalus opalus (Martyn, 1784) (S, L. 4).
Micrelenchus caelatus caelatus (Hutton, 1884) (P).
Micrelenchus caelatus bakeri Fleming, 1947 (N.G.H. 2, 25, 34, 36, 39, 43, 75, 80).
Micrelenchus micans (Suter, 1897) (S, N.G.H. 36, 57, 80).
Micrelenchus dilatatus (Sowerby, 1870) (N.G.H. 34, 53).
Micrelenchus parcipictus Powell, 1946 (N.G.H. 34, 43).
Micrelenchus tenebrosus (A. Adams, 1853) (N.G.H. 34, L. 10).
Margarella pysegurensis Powell, 1939 (N.G.H. 24, 39, 50).
Venustas punctulata urbanior Finlay, 1926 (N.G.H. 49, 57).
Venustas punctulata ampla Powell, 1939 (L. 4, 12).
Venustas pellucida (Vallenciennes, 1846) (N.G.H. 57).
Zethalia zelandica (A. Adams, 1854) (L. 2, 6).
Antisolarium egeum (Gould, 1849) (G, N.G.H. 24, 25, 34, 41, 45, 54).
Loddereia nana hooki Fleming, 1948 (N.G.H. 2).
Liotella rotula (Suter, 1908) (P, N.G.H. 2, 76, 80).
Liotella polypleura (Hedley, 1904) (N.G.H. 2).
Lodderia eumorpha (Suter, 1908) (P).
Zalipis benthicola Powell, 1927 (P).
Cirsonella accelerans Fleming, 1948 (N.G.H. 53).
Lissotesta errata Finlay, 1926 (P).
Lissotesta benthicola Powell, 1927 (P).
Conjectura glabella (Murdoch, 1905) (S, N.G.H. 34, 63, 80, 82).
Orbilestella hincmou Mestayer, 1919 (P).
Argalista umbilicata Powell, 1926 (P).
Argalista fluctuata (Hutton, 1883) (P, N.G.H. 34, 35, 39, 41, 43, 57, 58, 67, 80).
Argalista crassicostata (Murdoch, 1905) (N.G.H. 67).
Lunella smaragda (Martyn, 1784) (L. 3, 6).
Modiola granosa (Martyn, 1784) (S, N.G.H. 25, 34, 35, 41, 50, 57, 63, 67, L. 2, 3, 4, 6, 7, 9).
Astraea heliotropium (Martyn, 1784) (N.G.H. 34, 35, 49, 57, 58, 63, 75, L. 3, 5).
Cookia sulcata (Martyn, 1784) (N.G.H. 57, L. 4, 6, 9).
Notocrater craticulata (Suter, 1908) (S,P, N.G.H. 3, 40, 58, 80).
Cocculina certae Fleming, 1948 (N.G.H. 3, 39, 52, 58, 75, 80, 83).
 "Cocculina" n.sp (N.G.H. 3, 35, 58, 75, 80, 82, 83, 84).
Patelloida corticata (Hutton, 1880) (N.G.H. 34, 39, 40, 53, 54, L. 6, 7, 15).
Asteracmea suteri (Iredale, 1915) (S,G, N.G.H. 24, 34, 36, 39, 40, 41, 67, 76, 80).
Radiacmea inconspicua (Gray, 1843) (N.G.H. 24, 50, 57, 63, 80, L. 7).
Notoacmea (Parvacmea) daedala (Suter, 1907) (G, N.G.H. 24, 34, L. 7, 15).

- Notoacmea (Conacmea) parviconoidea* (Suter, 1907) (N.G.H. 1, 24, 63, L. 7, 9).
Notoacmea pileopsis sturnus (Hombr. and Jacq., 1841) N.G.H. 57, 80).
Atalacmea fragilis (Sowerby, 1823) (G, N.G.H. 40, 41, L. 15).
Cellana radians (Gmelin, 1791) (L. 6, 9).
Cellana stellifera (Gmelin, 1791) (L. 3).
Cellana redimiculum (Reeve, 1854) (L. 4).
Cellana ornata (Dillwyn, 1817) (L. 6).
Cellana sp. (N.G.H. 63, 80).
Melarhaphe oliveri Finlay, 1930 (N.G.H. 80).
Melarhaphe cincta (Q. and G., 1833) (N.G.H. 41, L. 2, 7, 10).
Macquariella aucklandica Powell, 1933 (N.G.H. 80).
Zelaxitas fiordlandica Fleming, 1948 (G).
Zelaxitas rissoaformis Powell, 1939 (G).
Risselopsis varia (Hutton, 1873) (G, N.G.H. 34, 41, 80, L. 7).
Zeradina (Radinista) corrugata (Hedley, 1904) (P).
Subonoba foveauxiana (Suter, 1898) (S,G, N.G.H. 4).
Subonoba fumata (Suter, 1898) (S,G, N.G.H. 24, 34, 39, 41, 53, 58, 80).
Subonoba insculpta (Murdoch, 1905) (S, N.G.H. 80).
Estea subfusca (Hutton, 1873) (S,P, N.G.H. 2, 34, 39, 41, 43, 52, 53, 54, 57, 58, 80, 83, L. 7).
Estea rufoapicta (Suter, 1908) (P).
Scalaronoba costata Powell, 1927 (P).
Haurakia huttoni (Suter, 1898) (P, N.G.H. 65, 67, 80).
Mercelina plaga Finlay, 1926 (S,P,G, N.G.H. 24, 34, 39, 41, 43, 53, 54, 58, 63, 67, 76, 80, 81, 82, L. 7).
Anabathron foliatum (Suter, 1908) (N.G.H. 80).
Linemera gradatoidea Finlay, 1930 (N.G.H. 46, 52, 82, 83).
Nobolira cf. finlayi Powell, 1930 (N.G.H. 2).
Nobolira hincmoa Fleming, 1948 (N.G.H. 80).
Lironoba suteri (Hedley, 1904) (P, N.G.H. 67).
Notosetia simplex (Powell, 1927) (P).
Notosetia porcellana (Suter, 1908) (P).
Notosetia lamprea (Suter, 1908) (P).
Notosetia benthicola Powell, 1927 (P).
Notosetia infecta (Suter, 1908) (P, N.G.H. 2, 80).
Notosetia lubrica (Suter, 1898) (P).
Notosetia microstriata (Murdoch, 1905) (P).
Notosetia verecunda (Suter, 1908) (P, N.G.H. 57).
Notosetia neozelanica (Suter, 1898) (P,G, N.G.H. 2, 39, 58, 63, 80).
Notosetia retusa Powell, 1927 (P).
Notosetia stewartiana (Suter, 1908) (P).
Scrobs cf. elongatus Powell, 1927 (P).
Epigyrus striatus Powell, 1927 (P).
Dardanula roseola Iredale, 1915 (S,P, N.G.H. 24, 34, 36, 39, 41, 53, 58, 76, 80).
Dardanula limbata (Hutton, 1883) (S, N.G.H. 34, 35, 41, 58).
Dardanula olivacea (Hutton, 1882) (N.G.H. 24, 41, 43, 53, 57, 58, 80).
Brooksena succincta (Suter, 1908) (P).
Rissoina chathamensis (Hutton, 1873) (G, N.G.H. 34, 36, 39, 41, 50, 53, 57, 58, 63, 80, L. 7).

- Potamopyrgus antipodum* (Gray, 1843) (N.G.H. 1, 56, 84).
Specula styliformis (Suter, 1908) (P).
Specula dissimilis (Suter, 1908) (P).
Specula odhneri Powell, 1927 (P).
Sundaya tuberculata Powell, 1927 (P).
Zaclys sarissa (Murdoch, 1905) (N.G.H. 57).
Notosinister (Cantor) luteus (Suter, 1908) (P, N.G.H. 80).
Notosinister (Terebriphora) huttoni (Suter, 1908) (P).
Notosinister fascelinus (Suter, 1908) (N.G.H. 80).
Cacum digitulum Hedley, 1904 (P, N.G.H. 41).
Maoricolpus roseus (Q. and G., 1834) (S, N.G.H. 25, 34, 41, 43, 45, 49, 50, 53, 57, 58, 67, L. 2, 3, 4, 9, 11).
Stiracolpus aff. *symmetricus* (Hutton, 1873) (N.G.H. 3, 25, 44, 45, 46, 52, 54, 55, 56, 57, 58, 63, 65, 67, 75, 80, 82).
Struthiolaria papulosa gigas Sowerby, 1842 (N.G.H. 34).
Zeacrypta monoxyla (Lesson, 1830) (N.G.H. 45, 52).
Sigapatella novaezelandiae Lesson, 1830 (G, N.G.H. 50, 55, 63, 80, L. 7).
Zegalerus tenuis (Gray, 1867) (N.G.H. 1, 25).
Tanca zelandica (Q. and G., 1832) (G, N.G.H. 56, 80, 82, L. 2).
U'berella vitrea (Hutton, 1873) (P, N.G.H. 25, 34, 39, 41, 43, 45, 46, 50, 53, 55, 80).
Lamellaria ophione Gray, 1850 (N.G.H. 80).
Trichosirius aff. *cavotocarinatus* (Laws, 1940) (G, N.G.H. 49, 80).
Argobuccinum tumidum (Dunker, 1862) (L. 4, 10).
Murdochella alacer Finlay, 1926 (P).
Zerotula bicarinata (Suter, 1908) (P).
Zerotula nautiliformis Powell, 1927 (P).
Chemnitzia zelandica Hutton, 1873 (P).
Chemnitzia sp. (N.G.H. 24, 25, 57).
Linopyrga rugata (Hutton, 1886) (P).
Besla subrugata (Powell, 1927) (P).
Odostomia pudica Suter, 1908 (G, N.G.H. 3, 67).
Agatha georgiana (Hutton, 1885) (N.G.H. 34, 57, 58, 63).
Eulimella sp. (N.G.H. 23, 34).
Balcis otagoensis (Powell, 1927) (P).
Austromitra rubiginosa (Hutton, 1873) (N.G.H. 34, 36, 41, 43, 53).
Buccinulum (Euthrena) strebeli exsculptum Powell, 1929 (S, N.G.H. 63, L. 10, 14, 15).
Austrofusus glans subsp. (N.G.H. 49).
Eucominia nassoides foveauxana Powell, 1946 (N.G.H. 3).
Eucominia nassoides haroldi Powell, 1946 (S, N.G.H. 25, 34, 67, L. 3, 11).
Fax powelli Fleming, 1948 (S, N.G.H. 2, 34, 55, 80, 81, 84).
Poirieria zelandica (Q. and G., 1833) (N.G.H. 25, 39).
Zeatrophon ambiguus (Philippi, 1844) (N.G.H. 34).
Zeatrophon aff. *caudatulus* Finlay, 1930 (N.G.H. 34).
Zeatrophon aff. *pulcherrimus* Finlay, 1930 (N.G.H. 80).
Lenitrophon convexus (Suter, 1909) (N.G.H. 80).
Xymene plebejus (Hutton, 1873) (N.G.H. 80, L. 7).
Arymene pumilus (Suter, 1899) (P).
Arymene aff. *corticatus* (Hutton, 1873) (N.G.H. 34, 53, 57, 67, 82, L. 7).
Comptella curta (Murdoch, 1905) (N.G.H. 67).

- Terefundus crispulatus* (Suter, 1908) (P, N.G.H. 37, 39, 83).
Terefundus n.sp. (N.G.H. 39, 83).
Terefundus (*Minortrophon*) *crassiliratus* (Suter, 1908) (P).
Lepsis haustum (Martyn, 1784) (L. 6, 7, 9).
Lepsiithais squamatus (Hutton, 1878) (N.G.H. 2, 63, L. 4, 6, 7, 15).
Zeadmete trailli (Hutton, 1873) (P).
Zemitrella sulcata (Hutton, 1873) (N.G.H. 43, 67).
Zemitrella choava (Reeve, 1859) (N.G.H. 34, 41, 43, 45, 67, 80).
Zemitrella cf. *finlayi* Powell, 1933 (N.G.H. 2, 24, 36, 80).
Paxula leptalca (Suter, 1908) (N.G.H. 80).
Liratilina conquisita nestoris Fleming, 1948 (N.G.H. 47).
Liratilina angulata (Suter, 1908) (N.G.H. 53).
Microvoluta biconica (Murdoch and Suter, 1906) (N.G.H. 39, 46, 49, 54, 63).
Baryspira (*Pinguispira*) *southlandica* Fleming, 1948 (G, N.G.H. 54).
Marginella albescentis Hutton, 1873 (P, N.G.H. 25, 34, 41, 45, 80).
Marginella stewartiana Suter, 1908 (P).
Fenestrosyrinx nexilis recens Fleming, 1948 (G, N.G.H. 39, 52, 55).
Fenestrosyrinx gratiosa Suter, 1908 (P, N.G.H. 51, 52, 80).
Aoteadrillia wanganuiensis chordata (Suter, 1908) (N.G.H. 46, 55, 63).
Splendrillia aotearica Finlay, 1930 (N.G.H. 46, 63).
Neoguraleus murchisoni (Finlay, 1924) (G, N.G.H. 45, 75, L. 7).
Liracraea cf. *subantarctica* Powell, 1942 (N.G.H. 1).
Stilla fiordlandica Fleming, 1948 (G, N.G.H. 2, 25, 80).
Stilla delicatula Powell, 1927 (P).
Stilla flexicostata (Suter, 1899) (P).
Pervicacia tristis (Deshayes, 1859) (N.G.H. 54).
Pervicacia flexicostata (Suter, 1909) (N.G.H. 76).
Diacria trispinosa (Lesueur, 1821) (N.G.H. 63).
Cleodora compressa Souleyet, 1852 (G).
Spiratella helicoides (Jeffreys) (P).
Embolus inflatus (d'Orbigny, 1836) (N.G.H. 39, 76, 80).
Cylichna striata (Hutton, 1873) (P).
Austrodiaphana colei Fleming, 1948 (N.G.H. 54, 80).
Philinc cf. *umbilicata* Murdoch and Suter, 1906 (N.G.H. 80).
Philinc auriformis Suter, 1909 (S, N.G.H. 57).
Marinula striata Odhner, 1924 (G, N.G.H. 80).
Amphibola crenata (Martyn, 1784) (L. 10, 13, 14).
Gadinalea nivea (Hutton, 1878) (L. 7).
Siphonaria cookiana Suter, 1909 (S).
Siphonaria zelandica Q. and G., 1833 (L. 6).
(Nudibranchs have not been listed.)

AMPHINEURA:

- Ischnochiton circumvallatus* (Reeve, 1847) (S).
Terenochiton aff. *inquinatus* (Reeve, 1847) (N.G.H. 34, 36, 43, 80).
Icoplax punicea (Gould, 1846) (N.G.H. 34).
Icoplax sulcata (Suter, 1907) (S).
Lorica haurakiensis Mestayer, 1921 (S, N.G.H. 85, 57).
Cryptoconchus porosus Burrow, 1815 (L. 15).
Acanthochiton zelandicus amplificatus Iredale and Hull, 1930 (N.G.H. 34).
Notoplax violacea (Q. and G., 1835) (L. 15).
Craspedochiton rubiginosus (Hutton, 1872) (N.G.H. 30, 34).

Anthochiton canaliculatus (Q. and G., 1835) (N.G.H. 34, 54, 57).

Amaurochiton glaucus (Gray, 1828) (L. 15).

Sypharochiton pelleris (Q. and G., 1835) (L. 1, 15).

Onithochiton neglectus Rochebrune, 1881 (N.G.H. 34, 57).

SCAPHOPODA:

Dentalium nanum Hutton, 1873 (N.G.H. 25, 37, 39, 46, 51, 63, 65, 75, 80).

Fissidentalium zelandicum (Sowerby, 1860) (N.G.H. 25).

Laevidentalium cf. *ecostatum* (Kirk, 1880) (N.G.H. 37).

Cadulus delicatulus Suter, 1913. (S. N.G.H. 3, 23, 25, 35, 37, 39, 43, 44, 45, 46, 51, 54, 55, 58, 75, 80, 81, 83).

REFERENCE TO SYMBOLS AND LOCALITIES

S—Recorded from Fiordland area by Suter (1913), but not seen in present revision.

P—Listed from 100 fathoms and 170 fathoms off Puysegur Point by Powell (1927).

G—George Sound, entrance, in 34 fathoms (N.Z. Government steamer *Matai*, 1935); slightly muddy coralline shell sand.

NEW GOLDEN HIND BOTTOM STATIONS*

N.G.H. 1.—Revolver Arm, Preservation Inlet, 13 fathoms, black carbonaceous mud with granular fragments, leaves, and bark.

N.G.H. 2.—Narrows, Long Sound, Preservation Inlet, 19 to 24 fms.

N.G.H. 3.—Upper end of Narrows, Long Sound, Preservation Inlet, 39 fathoms, medium to fine shell sand.

N.G.H. 23.—Head of Long Sound, Preservation Inlet, 11 fathoms, black highly organic mud.

N.G.H. 24.—South-east of Chalky Island, Chalky Sound, 30 fathoms, medium shell sand, shells.

N.G.H. 25.—Northport Anchorage, Chalky Sound, 11 fathoms, sandy grey mud.

N.G.H. 34.—Northport, one-quarter mile north-east of anchorage; 4 to 8 fathoms, muddy shell sand.

N.G.H. 35.—Edwardson Sound, opposite Little Island, 24 fathoms, muddy shell sand.

N.G.H. 36.—Entrance to Northport, north of Little Island, 8 fathoms, two-inch nodules of coralline algae.

N.G.H. 37.—Cunaris Sound, opposite mouth of Carrick River, 34 fathoms, highly organic green-grey sandy mud with granite grit and leaves.

N.G.H. 39.—Edwardson Sound, opposite entrance to Northport, 58 fathoms, oolitic mud with grit and shell fragments.

N.G.H. 40.—Between Cape Providence and Passage Island, 28 fathoms, fine comminuted shell fragments.

N.G.H. 41.—Northport, Chalky Sound, 7 fathoms, muddy shell sand.

N.G.H. 43.—Northport, Chalky Sound, 2 fathoms, sandy gritty mud.

*Details are presented only for those stations from which molluscs have been identified; about half the total number of samples have been examined.

- N.G.H. 44.—Cascade Cove, Dusky Sound, 18 fathoms, very carbonaceous mud with many leaves, twigs, and with fine grit.
- N.G.H. 45.—Facile Harbour, Dusky Sound, 12 fathoms, muddy shell sand.
- N.G.H. 46.—Opposite mouth of Facile Harbour, Dusky Sound, half-way to Five Finger Peninsula, 36 fathoms, medium dark sand with angular granite fragments.
- N.G.H. 47.—Between Parrot Island and Five Finger Peninsula, Dusky Sound, 42 fathoms, slightly muddy medium sand, few shell fragments.
- N.G.H. 49.—North-east of Parrot Island, Dusky Sound, 35 fathoms, slightly muddy shell grit, with shells.
- N.G.H. 50.—Between Parrot and Pigeon Islands, Dusky Sound, 8 to 11 fathoms, rock with patches of shell sand and grit.
- N.G.H. 51.—Between Pigeon Island and Whidbey Point, 45 fathoms, dark green-grey slightly oolitic mud.
- N.G.H. 52.—Boat passage east of Pigeon Island, 2 to 5 fathoms, rock with patches of sediment.
- N.G.H. 54.—Opposite entrance to Cormorant Cave, Dusky Sound, 2 to 4 fathoms, muddy sand.
- N.G.H. 55.—One mile north-east of Whidbey Point, 31 fathoms, greenish-brown, slightly muddy fine sand.
- N.G.H. 56.—Supper Cove Anchorage, head of Dusky Sound, 10 fathoms, carbonaceous mud with little sand.
- N.G.H. 57.—West-end of Channel inside Oke Island, Dusky Sound, 10 to 13 fathoms, rock with patches of mud.
- N.G.H. 58.—Middle of Basin inside Oke Island, opposite stream delta, 29 fathoms, sandy mud.
- N.G.H. 59.—East-end of Channel inside Oke Island, 15 to 40 fathoms, rock, patches of gritty sand.
- N.G.H. 63.—One chain and a half east of southern point of Breaksea Island, Breaksea Sound, 22 fathoms, coarse shell sand.
- N.G.H. 65.—Half a mile off end of Breaksea Island, 41 fathoms, dark medium sand with some fine shell sand.
- N.G.H. 67.—Off Gilbert Island, Breaksea Sound, 15 to 20 fathoms, rock, patches of shell grit.
- N.G.H. 75.—East channel between Johns Islands, Breaksea Sound, 32 fathoms, muddy shell sand.
- N.G.H. 76.—Daggs Sound, one to two miles west of Adieu Point, 25 to 28 fathoms, fine sand, little shell sand.
- N.G.H. 80.—Daggs Sound, inside a rock bar, 58 fathoms, dark green-grey mud, many small shells.
- N.G.H. 81.—Anchorage Arm, Daggs Sound, 47 fathoms, muddy carbonaceous grit, few shells.
- N.G.H. 82.—Few chains off end of Shelter Islands, Doubtful Sound, 73 fathoms, muddy fine shell sand.
- N.G.H. 83.—Centre of basin opposite Groznov Bay, Doubtful Sound, opposite stream delta, 38 fathoms, muddy fine sand, few shells.
- N.G.H. 84.—Anchorage, Macdonald Island, Bradshaw Sound, branch of Doubtful Sound, depth uncertain, probably about 15 to 25 fathoms, carbonaceous mud, few shells.

NEW GOLDEN HIND SHORE STATIONS

- L. 1.—Otago's Retreat, Preservation Inlet, inside spit on north side.
- L. 2.—Beach at mouth of Caesar Creek (Chalky Inlet).
- L. 3.—Beach at end of Cavern Head, Preservation Inlet.
- L. 4.—Moonlight Point.
- L. 5.—Saddle Hill Creek mouth.
- L. 6.—Near Spit Island, Preservation Inlet.
- L. 7.—10 ft. elevated beach, Spit Island.
- L. 8.—Wet Jacket Arm, Dusky Sound.
- L. 9.—Woodhen Cove, beach, Resolution Island.
- L. 10.—Goose Cove, Resolution Island, Dusky Sound.
- L. 11.—Sandy Bay, Pigeon Island, Dusky Sound.
- L. 12.—Various unlocalized beach specimens, Fiordland.
- L. 13.—Spit at end of Long Sound, Preservation Inlet.
- L. 14.—Under limestone boulders, east shore, Chalky Island.
- L. 15.—Under rocks at low tide, Secretary Island, opposite Banza Island, Dusky Sound.

ECOLOGY

The physiographic features of the New Zealand fiords which affect the mollusca are: (a) steep profiles from above high-tide mark to considerable depths, (b) limited development of beaches, estuaries, shore platforms, and other littoral biotopes, (c) the presence of moraine or rock bars separating locally "over-deepened" basins from the open sea, (d) high precipitation giving rise to a considerable inflow of fresh water, (e) small quantities of sediment brought in by the rivers, owing to the completeness of forest cover (plant remains are conspicuous in some of the shallower sediments, suggesting relatively high concentration of organic acids), (f) strong tidal currents which are more important than storm waves in the sheltered reaches of the longer fiords, (g) bare rock, coarse shell sands in scour channels, and other "hard" bottom, which are more common substratum than are fine sediments, owing to the limited sedimentation and the action of confined tidal bottom-currents.

SALINITY

Theoretically, physico-chemical conditions in deep land-locked arms of the sea, in areas of low evaporation, receiving quantities of cold fresh water from rivers, and separated by shallow rock bars from the open sea, should resemble, on a small scale, those of the Baltic (Sverdrup, Johnson, Fleming, 148-150, 657). In the Baltic type of circulation, a surface layer of cool water of relatively low salinity flows seawards over heavier, though warmer, more highly saline water at the bottom; bottom water must flow in over the rock bar at the mouth of the sound. If such a salinity stratification exists in the New Zealand fiords, it may have an effect on molluscan biotopes. The littoral faunas of the inner sounds (where the profile allows of their development) are poor in species and contain such euryhaline forms, tolerant of low salinity, as *Amphidesma australe*, *Lasaca* spp., *Austrovenus stutchburyi*, *Micrelenchus tenebrosus*, *Fractarmilla corrosa*, and *Amphibola crenata*. On the other hand, the bottom faunas of the sounds give little indication of reduced salinity, except for N.G.H. 23, 44, and 56 from 10 to 18 fathoms at the heads of Long Sound and Dusky Sound.

In the three samples named, dead shells of the estuarine *Paphies*, *Macomona*, *Austrovenus*, *Fracturinilla corrosa*, and of the fresh-water gastropod *Potamopyrgus* attest the proximity of stream deltas. On the other hand, even such land-locked stations as N.G.H. 2 and 3 (Narrows, Long Sound, 19 to 39 fathoms), 37 (Cunaris Sound, 34 fathoms), 57 to 59 (Wet Jacket Arm, 10 to 40 fathoms), 75 (Breaksea Sound, 32 fathoms), and 84 (Bradshaw Sound) contain mollusca which elsewhere in New Zealand are found chiefly on the open sea bottom or at least in non-estuarine bays. Among such may be noted members of the following genera: *Nuculana*, *Perrierina*, *Pallium*, *Condylocardia*, *Lima*, *Cardita*, *Scalpomactra*, *Longinactra*, *Nemocardium*, *Verticordia*, *Sinczona*, *Schizotrochus*, *Microclenchus* (*caelatus*), *Astraca*, *Argalista*, *Fax*, *Nobolira*, *Terefundus*, and *Stilla*. In general, then, if it is permissible to argue from the mollusca, it would appear that the entry of fresh stream-water into the fiords does not greatly affect the bottom faunas, which are characteristic of water of normal salinity, and that the Baltic type of circulation prevails.

TEMPERATURE

No detailed sea temperature study has been made in the fiords. If the circulation in them is of the Baltic type, the surface waters within the fiords should be cooler than the bottom waters and than the open sea outside. Analysis of the affinities of the Fiordland fauna shows that a number of forms are present which have not been recorded elsewhere in Southern New Zealand: such forms of northern aspect are entirely bottom dwellers and not from the littoral zone. It is difficult to assess the thermal facies of the shallow-water assemblages because the littoral biotopes are restricted, and their faunules poor in species, but *Eucominia* and *Margarella* are cool-water forms which do not live in deep water in Fiordland.

The warmer facies of Fiordland mollusca may be related, not so much to higher mean temperatures than those of south-eastern New Zealand as to less extreme minimum temperatures than are experienced in the latter area. L. Hutchins (1947) has recently emphasized the importance of maximum and minimum temperatures in limiting the distribution of maritime organisms. Study of the monthly surface-water temperature charts for New Zealand seas, prepared by the Marine Branch of the Meteorological Office shows that the surface-water east of the South Island is subjected to a much greater annual range of temperature than is that to the west, where the Nonotectian current maintains relatively constant temperatures.

The presence of northern forms in south-western New Zealand that are not recorded from Stewart Island or East Otago suggests that the Fiordland coast is more under the influence of the warm Nonotectian current, and less affected by the Subantarctic drift than is the rest of the southern end of New Zealand, and this suggestion is in accord with what little is known of the disposition of these currents.

DEPTH

The bottom samples come from depths of up to 73 fathoms. Any attempt to find the depth range of individual species is handicapped by the difficulty of separating "dead" from "living" shells in the samples. In the steep-sided fiords, gravitation of the dead shells of shallow-water molluscs into the over-deepened basins seems to be a regular

process, accentuated by the existence of seaweed-covered rock bars, within a few fathoms of sea-level, from which dead shells can fall almost vertically to depths of more than 50 fathoms. Flotation of pelecypod valves or air-filled small gastropods by rising tides in sheltered waters must also contribute to the mixing of dead shells. Thus a valve of *Paphirus largillierti*, a species living in moderate depths, is present in N.G.H. 82 (73 fathoms Doubtful Sound), and in N.G.H. 80 (58 fathoms, inside a rock bar, Daggs Sound) the following seaweed-inhabiting and littoral species are not uncommon: *Modiolus*, *Lasaea*, *Risellopsis*, *Melaraphis*, *Macquaricella*, *Notoacmea*, *Marinula*, and others. The upper limit of occurrence of species can be more reliably determined in this region where "depositing shorelines" are scarce.

The following are the minimum and maximum depths of occurrence in Fiordland of some of the commoner benthic molluscan shells:—

<i>Nuculana bellula</i> (A. Ad.)	.....	4 to 58 fathoms
" <i>Ovaleda</i> " <i>hamiltoni</i> Powell	.....	22 to 73 fathoms
<i>Nucinella maoriana</i> (Hedley)	.....	7 to 73 fathoms
<i>Bathyarca cybaca</i> (Hedley)	.....	34 to 73 fathoms
<i>Austrosarapta harrisonae</i> (Powell)	.....	8 to 73 fathoms
<i>Cosa costata</i> (Bern.)	.....	15 to 73 fathoms
<i>Perrierina</i> (4 spp.)	.....	19 to 58 fathoms
<i>Cyaniomactra problematica</i> Bern.	.....	14 to 58 fathoms
<i>Chlamys radiata</i> (Hutton)	.....	10 to 58 fathoms
<i>Lima zelandica</i> Sow.	.....	10 to 41 fathoms
<i>Cuna carditelloides</i> Suter	.....	45 to 73 fathoms
<i>Thyasira peroniana peregrina</i> Ired.	.....	2 to 58 fathoms
" <i>Tellina</i> " <i>huttoni</i> (Smith)	.....	10 to 36 fathoms
<i>Scalpomactra scalpellum</i> (Reeve)	.....	14 to 45 fathoms
<i>Dosinia greyi</i> Zitt.	.....	12 to 18 fathoms
<i>Notocallista multistrata</i> (Sow.)	.....	12 to 39 fathoms
<i>Taavera spissa</i> (Desh.) shore to 58 fathoms (single valves only in depths of more than 40 fathoms)		
<i>Nemocardium pulchellum</i> (Gray)	.....	12 to 73 fathoms
<i>Ascitellina urinatoria</i> (Suter)	.....	15 to 34 fathoms
<i>Eximiothracia vitrea</i> (Hutton)	.....	14 to 39 fathoms
<i>Parvithracia suteri</i> Fin.	.....	24 to 73 fathoms
<i>Myadora antipodum</i> Smith	.....	4 to 58 fathoms
<i>Mydora subrostrata</i> Smith	.....	22 to 73 fathoms
<i>Schizotrochus</i> 2 spp.	.....	24 to 58 fathoms
<i>Emarginula striatula</i> (Q. and G.)	.....	2 to 73 fathoms
<i>Coclotrochus tiaratus</i> (Q. and G.)	.....	2 to 58 fathoms
<i>Thoristella benthicola</i> Fin.	.....	2 to 22 fathoms
<i>Microclenchus caelatus bakeri</i> Fleming	.....	2 to 58 fathoms
<i>Antisolarium egeum</i> (Gould)	.....	2 to 34 fathoms
<i>Argalista fluctuata</i> (Hutton)	.....	4 to 58 fathoms
<i>Subonoba fumata</i> (Suter)	.....	5 to 58 fathoms
<i>Estea subfusca</i> (Hutton)	.....	shore to 58 fathoms
<i>Haurakia huttoni</i> (Suter)	.....	15 to 58 fathoms
<i>Rissoina chathamensis</i> (Hutton)	.....	shore to 58 fathoms
<i>Maoricolpus roseus</i> (Q. and G.)	.....	shore to 35 fathoms
<i>Stiracolpus</i> aff. <i>symmetricus</i> (Hutton)	.....	10 to 73 fathoms
<i>Uberella vitrea</i> (Hutton)	.....	2 to 58 fathoms
<i>Microvoluta biconica</i> (M. and S.)	.....	14 to 28 fathoms
<i>Fenestrosyrinx</i> 2 spp.	.....	22 to 58 fathoms

BOTTOM COMMUNITIES

Powell (1937b) has shown that the texture of the substratum is a more important factor than depth alone in controlling the distribution of animal communities in Auckland and Manukau harbours. Adequate discussion of the Fiordland bottom communities must be postponed until mechanical grading of the sediments is possible; nevertheless, by comparing the sediments and faunas with the formations and associations described by Powell, some useful analogies may be drawn.

COMMUNITIES IN A SOFT MUD SUBSTRATUM: Powell's *Echinocardium* formation is the most extensive biotope in Auckland Harbour. In Fiordland a small number of samples were collected (N.G.H. 1, 23, 44, 45, 84) in which the texture is described as dominantly muddy, and in which occurs a fauna with some affinities to that described by Powell. Irregular echinoids are present in at least some samples, but the dominant pelecypod *Dosinia lambata* has not been recorded. Instead, *Dosinia greyi* (a secondary species in the formation in Auckland) is here at least locally important, and "*Tellina*" *huttoni* locally approaches dominance. *Tawera spissa*, *Neilo australis*, *Leptomya reticularia*, *Cadulus*, and *Melliteryx*, which are all found in the formation at Auckland, are present in the Fiord area. The presence of *Echinocardium*, which Powell has shown to be intolerant of salinity below 34 per cent., is further indication of the relatively euhaline benthic conditions in land-locked fiords.

SANDY MUD AND MUDDY SAND SUBSTRATUM: Several different assemblages share this general type of substratum. In some (N.G.H. 34, 41, 53) *Maoricolpus* is dominant, *Tawera* is often important, and *Coclotrochus* present in numbers, suggesting that a facies of the *Maoricolpus* formation is represented. The dominant pelecypods of that formation at Auckland (*Dosinula*, *Nucula harteigiana*, *Paphirus*) are nowhere dominant in the Sounds. Elsewhere, sandy-mud substratum supports faunas dominated by either *Nemocardium pulchellum* or *Nuculana bellula*.

SHELLS AND SAND WITH LITTLE MUD: Such relatively coarse-textured biotopes are characteristic of the tide-scoured channels at fiord entrances or between islands. No community quite comparable with Powell's formation 3 (*Tawera* and *Glycymeris*) has been seen from the fiords, but the conditions under which shell-sand substratum occurs—in positions of tidal scour—and the fact that the substratum is often made up of the accumulated dead shells of the dominant organisms point to a genetic affinity with that formation. Nowhere has *Penericardia* been found dominant; it is, in fact, rare in the fiords. One characteristic biocenosis is dominated by *Cyamionactra*, the dead shells of which make up the bulk of the coarser fraction of such samples as N.G.H. 54. Another type of substratum, apparently rather widespread in southern New Zealand, consists of coralline shell-sand (with a small branching coral and pink actinarian), containing many dead small pelecypods such as *Austrosarepta* (in sample G); the biocenotic mollusca include *Antisolarium*, "*Tellina*" *huttoni*, and *Ascitellina*. *Scalpomactra* is dominant in some of the shell-sand facies.

BRACHIOPOD—*Chlamys* ASSOCIATION: At two stations, one (N.G.H. 2) in the channel of the Narrows (Long Sound), the other in the

channel inside Oke Island, Wet Jacket Arm, an association occurs closely akin to that described from Port Pegasus, Stewart Island, by Allan (1937, p. 160). In the fiord samples, the texture of the bottom is generally coarse, with pebbles and dead molluscan shells and lesser amounts of fine sediment. Brachiopods of several genera (*Neothyris*, *Liothyrella*, *Tegulorhynchia*, *Terebratella*) and *Chlamys radiata* are accompanied by numerous secondary species of mollusca, and by a species of *Flabellum* and the regular echinoid *Pseudechinus huttoni* Benham.

The association occurs in areas of strong currents where sediment is bypassed. Allan has noted the occurrence of similar associations throughout the latter half of the Tertiary.

CORALLINE ALGAE SUBSTRATUM: New Golden Hind sample 36 (entrance to Northport, north of Little Island, 8 fathoms) consists almost entirely of branching calcareous algae. The mollusca associated are few and chiefly thanatocoenotic: *Cardita aoteana*, *Dardanula roseola*, and a few *Amphicure* were the only biocoenotic forms noted.

AFFINITIES OF THE MOLLUSCAN FAUNA OF FIORDLAND

The study of the distribution of mollusca within the New Zealand region has largely centred around the naming of faunal provinces to emphasize the superficial differences between the faunas of different parts of New Zealand and its outlying islands. Detailed analysis of the ranges of the species comprising the faunas of single provinces and of the whole region has yet to be made, and the provincial boundaries in New Zealand proper—provisionally adopted by Finlay when he published Iredale's manuscript scheme, and modified by Powell (1937a)—will almost certainly be further modified. In the meantime, accumulation of precise range data is the best contribution that can be made to the problem.

The Fiordland area is part of the Forsterian Province as defined by Finlay (1925) and restricted by Powell, but most of the collections on which the conception of the Forsterian fauna is based come from Eastern Otago, Foveaux Strait, and Stewart Island. It may be profitable, therefore, to compare the Fiordland molluscan fauna with those of (a) Stewart Island, which has recently been the subject of a detailed report and check-list (Powell, 1939), and (b) whole Forsterian, for which a basic faunal list can be compiled from the distributional information in Powell's (1946b) check-list of New Zealand Recent Mollusca.

The Stewart Island list contains the names of 363 marine forms, and is considered by Powell a rich one for its latitude. The Fiordland list contains 342 names, and, in view of the small amount of collecting that has been done, it is probably incomplete. Comparison of the two lists shows that more than 80 species in the Fiordland list are not recorded from Stewart Island, and these include not only rare small species, and endemic representative forms, but common forms such as *Monia zelandica*, *Trichomusculus barbatus*, *Zemysia zelandica*, *Rochefortula reniformis*, *Dosimula zelandica*, *Myadora antipodum*, *Tugali suteri*, *Cavodiloma coracina*, *Melaraphe oliveri*, *Zeacrypta monoxyla*, *Sigapatella novaezelandiae*, and *Amphibola crenata*.

The Fiordland list contains about 30 genera which are not recorded from Stewart Island, and there are about the same number of Stewart Island genera not recorded from Fiordland. Further collecting in both areas will doubtless diminish these differences.

A comparison with the fauna of the rest of the Forsterian province must be less precise, because the only provincial faunal list available (compiled from the Forsterian records in Powell's (1946) check-list) includes the earlier Fiordland records. Also, to this basic provincial faunal list must be added the names of those Stewart Island mollusca (Powell, 1939) which have not been noted as occurring in the Forsterian in the check-list*. More than 60 species in the Fiordland list (including those from the Puysegur Point dredgings) are either (a) confined to the area or (b) not recorded elsewhere in the Forsterian, but have affinities elsewhere. Sixteen genera enter Southern New Zealand only in Fiordland or are endemic to Fiordland. The more important items in the Fiordland faunule are listed and their affinities indicated:

Nucula aff. *gallinacea*: Described from Hen and Chickens Island.

Poroleda: Other recent occurrences of the genus are from northern New Zealand.

"*Ovalceda*" *hamiltoni*: No recent records outside Fiordland.

Austrotindaria: So far endemic to Fiordland.

Perrierina: The genus is almost confined to southern waters.

Perrierina perstriata: Closest to North Auckland *substriata*.

Trichomusculus: Enters Southern New Zealand only in Fiordland.

Dacrydium: Enters Southern New Zealand only in Fiordland.

Chlamys suprasilis crepusculi: Related to *suprasilis* of eastern South Island.

Kidderia: The genus is dominantly subantarctic.

Kidderia aupouria fiordlandica: Related to North Auckland form.

Hamacuna gibbosa: Elsewhere only in North Auckland.

Condylocardia pectinata: Australia and Chatham Islands.

Taras zelandica: First record for Southern New Zealand.

Lasaca rossiana tutanckai: Related to Chatham Island and Subantarctic forms.

Mysella henryi: Closest to *larochci*, North Auckland.

Haliris setosa: Otherwise recorded in Northern New Zealand only.

Austroneacra: Genus otherwise recorded from North Auckland only.

Schizotrochus regius: Elsewhere known only from North Auckland.

Schizotrochus mantelli: With North Auckland and Australian affinities.

Tugali suteri: Not elsewhere recorded in Southern New Zealand.

Micrelenchus micans: Endemic to Fiordland.

Micrelenchus parcipictus: Endemic to Fiordland.

*The following species in the Stewart Island list are not noted as of Forsterian occurrence in the check-list: *Acar sandersonae*, *Costokidderia lyallensis*, *Benthocardia obliquata*, *Goniurysa concinna*, *Amphidesma subtriangulata*, *Dosinia anus*, *D. subrosea*, *D. maoriana*, *D. greyi*, *Offadesma angasi*, *Thoristella chathamensis*, *Maurca waikanae*, *Cellana stellifera*, *Mercelina superba*, *Notosetia verecunda*, *Scrobs elongatus*, *Larochella toreuma*, *Specula canaliculata*, *Notosinister infelix*, *Neojanacis perplexus* (omitted from check-list), *Cabestana spengleri*, *Xenophium pyrum*, *Zerotula hedleyi*, *Xymenella pusilla*, *Paxula paxillus*, *P. murchisoni*, *Alcithoe arabica*, *Zenopsis chariessa*, *Antimelatoma buehanani moorum*, *Neoguraleus amoenus*, *Pericardium tristis*, *Cavolina telemus*, *Pupa alba*, *Bouvieria aurantiaca*, *Siphonaria australis*, *S. cookiana*, *Ischnochiton luteoroseus*, *Terenoichiton inquinatus*, *Dentalium marwicki*. In addition, some 14 species from off Puysegur Point (Powell, 1927) have not been indicated as Forsterian, but for the present comparison they may be grouped with the Fiordland fauna.

Margarella pygmaea: Endemic to Fiordland.

Loxodonta nana pooki: Closest to North Auckland form.

Liotella rotula: A New Zealand Subantarctic species.

Cirsonella accelerans: Nearest *C. varicostata* Powell, North Auckland.

Cocculina cerata: Related to Australian species.

Nobolira: Genus present in Tasmania and North Auckland, but no other records from Southern New Zealand.

Notosinister (Cantor) luteus: Subantarctic.

Murchisonella alacer: Species (and genus) otherwise northern.

Fax: Genus recorded in Tasmania and North Auckland, but not elsewhere in Southern New Zealand.

Zeatrophon caudatus: Described from Auckland.

Liriatilia conquisita nestoris: Nominative race occurs in Northern New Zealand.

Baryspira southlandica: The southernmost representative of the genus*.

Fenestrosyrinx nexilis recens: Recent race of Pliocene species.

Stilla fiordlandica: Nearest to *S. paucicostata*, North Auckland.

Pervicacia flexicostata: Listed from Aupourian (North Auckland) only, in check-list.

Austrodiaphana: Affinities with S.E. Australia and Tasmania.

The differences between the molluscan fauna of Fiordland and that of the rest of the Forsterian, including Stewart Island, may be summed up as due chiefly to the presence of elements of either Australian derivation or of Aupourian (North Auckland) affinity. The distribution pattern of such genera as *Fax* and *Nobolira* (Eastern Australia, Fiordland, North Auckland), and perhaps of *Austroneaca* and *Poroleda* (Fiordland and Northern New Zealand) may be interpreted as evidence of the importance of the Notonectian current, flowing eastward across the south Tasman and then northward, as a vector of those marine organisms possessing the required vagility.

Genera and species which have their major development in, or are otherwise confined to, the subantarctic area, dominated by the influence of the west wind drift, are not so strong, numerically, in Fiordland as are those of trans-Tasman and Northern New Zealand affinity. The forms of inferred subantarctic origin include several which have extended into Northern New Zealand. The southern species in Fiordland are:

Lissarca stationis: Northernmost occurrence of this subantarctic genus in New Zealand.

Perricaria 4 spp.: Genus mainly southern; one sp. in N. Auckland).

Cyanomactra problematica: Southern in New Zealand, but genus is also Australian.

Kidderia 2 spp.: Genus mainly southern; one species in North Auckland.

Ferticopronus: Genus southern.

Lusaca rossiana: Species subantarctic, reaching Southern New Zealand.

Margarella: Subantarctic genus entering Southern New Zealand.

*Suter's (1913, p. 452) record of *B. australis* from Chalky Inlet requires confirmation; the specimens are not in the Suter Collection.

Macquariella: N.Z. Subantarctic genus entering southern New Zealand.

Specula: N.Z. Subantarctic genus entering southern New Zealand.

Cuitor: N.Z. Subantarctic subgenus entering southern New Zealand.

Eucominia nassoides: N.Z. subantarctic genus entering southern New Zealand.

Marinula striata: Subantarctic species entering southern New Zealand.

Without full statistical analysis of the distribution, extralimital affinities, and fossil ancestry of the whole recent New Zealand molluscan fauna, any assessment of the affinities and origin of the Fiordland faunule must be to a great extent subjective. With this reservation, the nature of the Fiordland faunule may be summarized as follows:—

- (1) A nucleus of endemic New Zealand elements, either fairly wide-ranging in New Zealand or restricted to southern New Zealand.
- (2) A smaller but important element with affinities with northern New Zealand or Australia, or with both.
- (3) A small subantarctic element.
- (4) A small endemic element.

These characteristics might justify erection of a further faunal province to emphasize the distinctions between Fiordland and the Forsterian Faunal Province of East Otago and Stewart Island. The usefulness of such a procedure would be questionable, particularly at present, when the faunal boundaries can be only arbitrarily drawn, and when data for other marine groups (no less important than mollusca) are deficient. It would seem of more value to local zoogeography to indicate the diverse provenance of faunal elements as a contribution towards the eventual elucidation of the dynamics of animal distribution.

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THE APPLICATION OF CONFLUENCE ANALYSIS TO AGRO-ECONOMIC SURVEYS

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Summary

This paper demonstrates, by means of bunch-maps, that confluence analysis may give correct conclusions not only when the relationships within subsets of variable are linear, but also when they are multiplicative.

INTRODUCTION

ONE of the objects of collecting agro-economic survey data is to estimate the effect, for example, of fertilizer management, expressed as area top-dressed with artificial fertilizer upon some index of productive efficiency such as production per acre. The obvious method of tackling this problem is to set up a multiple regression equation with the efficiency index as the dependent variable, and such factors as are being studied as the independent variables. Then, from this regression equation the effect on the dependent variable of altering in turn each of the independent variables may be estimated.

Unfortunately, Frisch's work¹ has shown that under certain conditions this relatively simple procedure may yield very misleading or even nonsensical results. Frisch's ideas are most easily explained using three variables as an example. Fitting a regression equation to three variables implies that the three variables lie in a plane surface and that one independent linear relationship exists between them. If, however, two independent linear relationships exist between the three variables, they will lie along a line. To attempt to fit a plane, in other words a regression equation having two independent variables, is obviously absurd, as any given line may lie in any of an infinite number of planes.

The mathematical theory underlying the fitting of the regression equation leads in this case to the indeterminate form $\frac{0}{0}$. In practice, however, to obtain this answer numerically the two conditions required are seldom both fulfilled. These conditions are that the observational data are exact and that there has been no rounding off in the computations. If either of these conditions is unfulfilled, the indeterminate

form will not appear and a fictitious determinacy generated either by observational or rounding-off errors would result.

It might be thought that some safeguard would be reflected by the standard errors of the regression coefficients. Such, however, is not the case, for the standard errors themselves come out in exact data and computations as an indeterminate. Frisch¹ and Richard Stone² both have interesting comments on this point.

The situation may obviously be worse when several variables are included in the analysis, as relationships might conceivably exist between different sub-sets of variables. In attempting to overcome these difficulties, Frisch developed what he termed "confluence analysis" which may be described briefly as an attempt to isolate and identify any independent linear relationship that may exist between any of the variables in the system. It is not feasible in this paper to give a detailed account of the theory and logic of confluence analysis and the following simplified discussion must suffice.

DISCUSSION

One of the basic ideas is that if there is an exact linear relationship between a set of variables, then the regression equations, obtained by making in turn each of the variables in the regression system the dependent variable, are equivalent. If (V_{ij}) be the correlation matrix and (R_{ij}) be its adjoint, then it is well known that the regression equation with the j^{th} variable as the dependent variable may be written (when the variables are standardized)

$$R_{1j} X_1 + R_{2j} X_2 + \dots + R_{jj} + \dots + R_{nj} X_n = 0$$

If there is an exact linear relationship between the variables then the matrix (V_{ij}) is singular and by considering the characteristic equation of (R_{ij}) it is easily seen that (R_{ij}) is of rank one, and hence its rows (or columns, because of its symmetrical properties) are proportional. Hence the regression coefficient between X_2 and X_j , when X_j has been chosen as the dependent variables as b_{ij}^k may be written,

$$b_{ij}^k = \frac{R_{jk}}{R_{2k}}$$

Hence, as (R_{jk}) is of rank one, $b_{ij}^1 = b_{ij}^2 = \dots = b_{ij}^n$.

The method of computing all the various R_{jk} for all possible subsets is known as tilling, and once the tilling tables are complete the bunch-maps may be drawn in the following way. To plot the beam of the k^{th} variable for the regression between the i^{th} and j^{th} variables, R_{ik} is measured along the horizontal and R_{jk} along the vertical. A line is drawn to connect this point with the origin. If R_{ik} and R_{jk} are of the same sign, R_{jk} is measured vertically down; if of opposite signs, upwards. Hence it will be seen that b_{ij}^k is given by the slope of the lines. This means then that if a linear relationship exists, all the beams will lie along the same line.

On the other hand, should two or more linear relationships exist between the variables, some of the R_{ik} and R_{jk} will be both zero and if observational and/or rounding-off errors exist, then the b_{ij}^k will be

fictitiously determined by more or less random errors: In this case, the slope of the beams will be rather random and far from bunched.

Five variables from the Whangarei county data have been selected, as these variables provide a good illustration of the technique. The correlation matrix is given below.

	1	2	5	8	10
1	1.000	.286	— .133	.543	— .051
2		1.000	— .522	.911	— .007
5			1.000	— .504	.773
8				1.000	.001
10					1.000

For reasons of space, the tilling tables are omitted and the complete bunch-maps given in Figs. 1 to 7.

From the bunch-maps it will be seen that of the simple two-variable subsets only (2, 8) and (5, 10) give comparatively tight bunches. Of the three-variable subsets, (2, 5, 10), (5, 8, 10), and (1, 2, 8), all have fairly narrow beams and hence the variables in these sets are suspected to be closely related. To check this conjecture, the subset (2, 5, 8, 10) should show definite explosion as there will now be two relationships involved. Reference to the bunch-maps shows that five of the six bunches of this subset have definitely exploded. The remaining four-variable subsets do not show this explosive tendency, which is as it should be. In the complete set (1, 2, 5, 8, 10) all the ten maps (except (1, 8) and (5, 10) show very definite explosion, and it is highly significant that in both (5, 10) and (1, 8) and 8 in (5, 10) lie outside the sector of the principal beams.

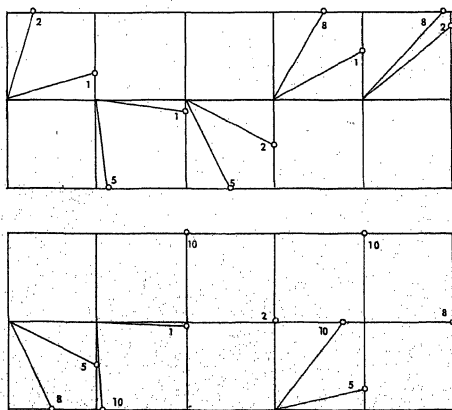


Fig. 1

So far, these five variables have been considered without reference to their actual nature. When the actual nature of the variables is considered, the position is very interesting. The five variables are

- (1) Production per cow
- (2) Carrying capacity
- (5) Logarithm of cultivated area
- (8) Production per acre
- (10) Number of cows

for 510 "pure" dairy farms of flat topography in the Whangarei county. The logarithm of the cultivated area was chosen to make area regressions more nearly linear. Consider the subset (2, 5, 10) which gives a narrow bunch. Carrying capacity was defined as the total number of sheep units per acre of cultivated area. When this relationship was first located, its validity was disputed until it was recalled that a "pure" dairy farm was defined as one where 90 per cent

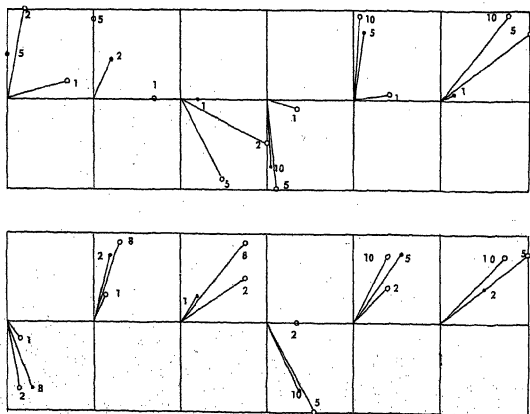


FIG. 2

of the stock carried was dairy stock. Hence the total sheep units were almost equivalent to the number of cows. This point was first overlooked because included in the survey data (but not used in this particular analysis) were a large number of mixed farms where the total number of sheep units was definitely not equivalent to the number of cows. Similarly, it is easily seen that carrying capacity is virtually equivalent to production per acre divided by production per cow, thus indicating the relationship in the subset (1, 2, 8). Finally, as the number of cows is highly correlated ($r > 0.9$) with total production, the production per acre is almost equivalent to carrying capacity and to number of cows divided by area, thus giving

the relationship in subset $(5, 8, 10)$ and the two relationships in $(2, 5, 8, 10)$.

The above considerations have a decided theoretical interest in that the theory behind confluence analysis stipulates *linear* relationships, whereas the ones given above are multiplicative. Despite this, confluence analysis has led to correct findings.

Undoubtedly, confluence analysis is a very useful tool, particularly when indeterminacy is liable to arise, but unfortunately, the amount of computation needed when the variables exceed five or six becomes somewhat complicated and the number of bunch-maps to be drawn, examined, and interpreted, excessive. For example, with an eight-variable system, the computations involve almost twelve thousand multiplications and two hundred and fifty-five maps. Each successive variable more than doubles the amount of computation and almost exactly doubles the number of maps.

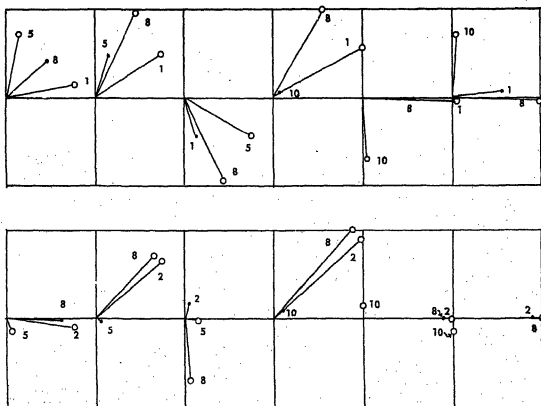


Fig. 3

Some sort of compromise is required. Frisch himself pointed out the possibility of using what he terms, at Belz's suggestion, scatterances. The scatterance of a set of variables is simply the value of their correlation matrix. The amount of computation involved in evaluating scatterances is, by Olav Reiersøl's method,³ very much less than that required for a complete confluence analysis. In the first section of his work on confluence analysis, Frisch¹ has given rules on how to work with and interpret scatterance.

It is felt, however, that for a preliminary reconnaissance, Frisch's methods are rather too elaborate and it is suggested that a slightly modified procedure described by Hotelling⁴ should be employed. The

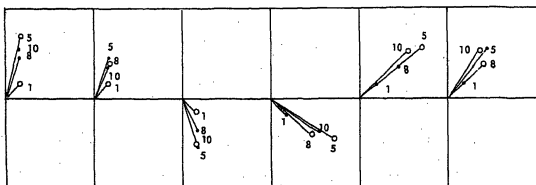
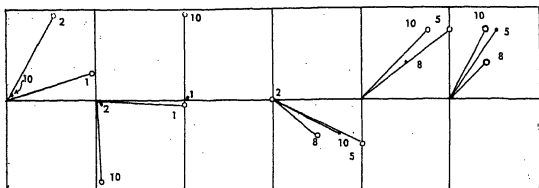


FIG. 4

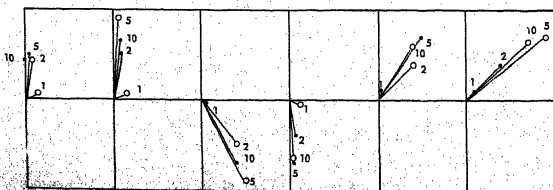
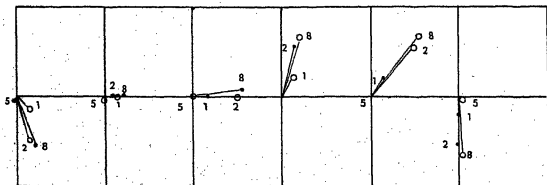


FIG. 5

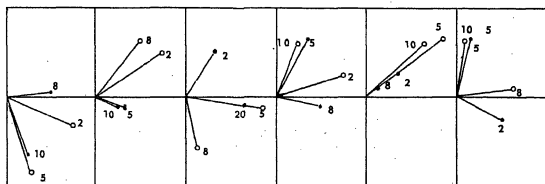
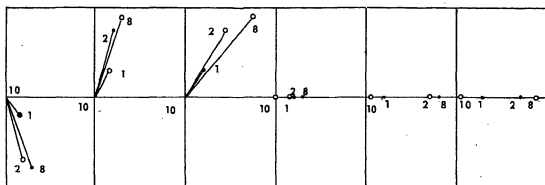


FIG. 6

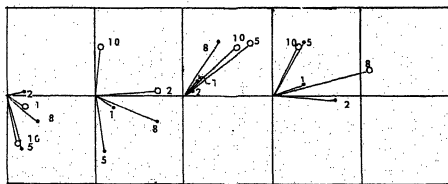
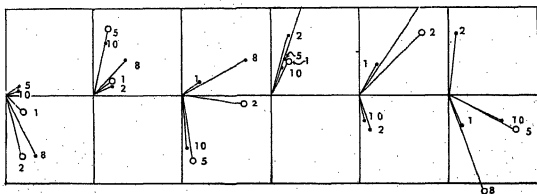


FIG. 7

basis of this method is to calculate the multiple correlation coefficient for every possible regression and then select the smallest set of variables that has the highest multiple correlation for the variable in which the investigator is particularly concerned. This, of course, is a much simpler procedure than that advocated by Frisch. It does not entirely eliminate the possibility of reaching nonsensical results, but it makes possible the submission of this small subset of variables to a full confluence analysis if necessary. The multiple correlations are, to the best of the writer's knowledge, most expeditiously computed by Reiersøl's method.

If the bunch-map shows no sign of explosion or multicollinearity, the question of inclusion of a new variable may be tested in the following way. If the square of the multiple correlation is only slightly increased (it can never be decreased) by the inclusion of the extra variable, then its insertion is not worthwhile, for the square of the multiple correlation (R^2) is a measure of the amount of variation in the dependent variable accounted for by the independent variables. More formally and in more generality, the procedure can be described by means of an analysis of variance table in a manner similar to that described by Hotelling¹ except that he used regression coefficients and the writer prefers R^2 . Let there be groups of observations and suppose that the multiple correlation of p independent variables is R_p . Also, suppose that when a further q independent variables are inserted that the multiple correlation is R_{p+q} . Then the analysis of variance (assuming that all variables both dependent and independent are in standard measure) is as follows:

VARIATION	D.F.	S.S.	M.S.
q additional variables	q	$R^2_{(p+q)} - R^2_p$	$\frac{R^2_{(p+q)} - R^2_p}{q} = S_1^2$
Residual	$n - p - q - 1$	$1 - R^2_{(p+q)}$	$\frac{1 - R^2_{(p+q)}}{n - p - q - 1} = S_2^2$
Total	$n - 1$	1	

Then the ratio $F = \frac{S_1^2}{S_2^2}$ is tested in the normal fashion with the degrees of freedom as given above.

To illustrate what has been discussed above, the data provided by the seven-year averages of 152 dairy farms in the Whangarei county is considered. The eight variables chosen are:

- (1) Butterfat per cow
- (2) Carrying capacity (total sheep units per acre)
- (3) Soil rating
- (4) Percentages area hay
- (5) Logarithm of cultivated area
- (6) Percentage area topdressed with artificial fertilizer
- (7) Percentage area limed
- (8) Production per acre

Consider first butterfat per cow. Then the squares of the multiple correlation for the various subsets are given below.

	R^2		R^2		R^2		R^2
12	.13	145	.12	158	.33	1456	.17
13	.13	126	.18	168	.34	1237	.17
14	.07	136	.16	178	.33	1247	.17
15	.05	146	.16			1347	.15
16	.13	156	.14	1234	.16	1257	.16
17	.09	127	.15	1235	.15	1357	.14
18	.33	137	.13	1245	.15	1457	.16
		147	.13	1345	.14	1267	.18
123	.15	157	.10	1236	.19	1367	.17
124	.15	167	.14	1246	.19	1467	.17
134	.11	128	.51	1346	.18	1567	.15
125	.13	138	.33	1256	.18		
135	.10	148	.33	1356	.17		
				1678	.34		
1238	.52	1368	.34				
1248	.85	1468	.34				
1348	.34	1568	.36				
1258	.53	1278	.51				
1358	.36	1378	.33				
1458	.36	1478	.33				
1208	.52	1578	.33				
12348	.86	12568	.53	13578	.36		
12358	.53	13568	.36	14578	.36		
12458	.85	14568	.36	12678	.52		
13458	.37	12378	.52	13678	.34		
12368	.52	12478	.86	14678	.34		
12468	.86	13478	.34	15678	.36		
13468	.34	12578	.52				

In the subsets of five variables, only those sets that have the variable 8 included have been listed, as the highest subsets, not including 8, gave R^2 as low as 0.19.

Since the addition of any further variable does not increase R^2 significantly, it will be seen that the subset 1248 contains almost all the available information concerning production per cow obtainable from the listed variables.

When carrying capacity is considered, the following results are shown:

21	.13	235	.47	238	.85	2346	.39
23	.20	245	.51	248	.85	2156	.48
24	.18	216	.26	258	.86	2356	.54
25	.38	236	.34	268	.85	2456	.55
26	.22	246	.31	278	.85	2137	.34
27	.17	256	.45			2147	.33
28	.85	217	.23	2134	.33	2347	.37
		237	.21	2135	.50	2157	.48
213	.27	247	.30	2145	.53	2357	.52
214	.25	257	.45	2345	.56	2457	.57
234	.29	267	.24	2136	.36	2167	.28
215	.43	218	.89	2146	.33	2367	.35
2467	.34						
2567	.47						
2138	.89						
2148	.97						
2158	.89						
2168	.89						
2178	.89						

ACKNOWLEDGMENTS

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FLUCTUATIONS AND SECULAR TREND OF NEW ZEALAND RAINFALL

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Summary

Rainfall over the Dominion and each island is summarized into an annual index, the 1911-40 mean being taken as 100. The dispersion of rainfall amongst stations in a given year is briefly discussed. The fluctuations in index from year to year are resolved into a longer period which correlates closely with the 11-year sunspot cycle and a shorter more irregular period averaging three years. The indices for 1863 to 1947 show a declining tendency at the average rate of at least four per cent and two per cent per century for the North and South Islands respectively, but such a trend implies a bias in the method of evaluating indices before 1890 and a reasonable adjustment increases these trend rates to about seven and three per cent per century.

INTRODUCTION

ALTHOUGH yearly rainfall totals are published regularly for all official recording stations in New Zealand, it is not easy to discover how the rainfall is changing from year to year if the country is considered as a whole. Individual records and their history need to be examined critically before they can be incorporated satisfactorily into some Dominion-wide index. The first object in this paper is to explain the method adopted for constructing annual indices and to provide the complete list of values so obtained. These will be the basis of the later discussion upon the character of the fluctuations shown in the recorded rainfall of New Zealand.

ANNUAL RAINFALL INDEX

Many investigations on rainfall are best started on a Dominion-wide basis and significant results can then be studied in more detail amongst records covering more restricted regions. To facilitate such studies it was considered desirable to have an annual index summarizing the rainfall over the whole of New Zealand. One great advantage of grouping many records into a single figure is that the importance of individual errors is minimized for, besides small errors in reading and recording, there may be some serious bias caused by the relocation of a rain-gauge or by the conditions of exposure being affected by expansion of buildings or altered with the gradual growth of trees and shrubs in the environs. As none of the longer rainfall records

in New Zealand can be considered perfectly homogeneous it is essential to consider several together before it is profitable to discuss secular variations. Although, whenever practicable, due allowance for site changes has been made by comparisons amongst overlapping records, the earliest gauges were too isolated for this method to be effective and further full details of their history were not always preserved.

Because of the great diversity in the absolute amount of rainfall received in different parts of the country, rainfall for each station is best expressed as a percentage of its long period average. The average of these percentages at stations spread over the country is then taken as the Dominion index for a given year. A similar procedure is followed in many other countries. To standardize the long period, the 30 years from 1911 to 1940 were chosen, and 108 stations in operation during that time were selected for their length, regularity and dispersion over the country. Any gaps in a record were interpolated by comparisons with records from the nearest stations and in this way these 108 records were made complete over these 30 years. As, with only a few exceptions, these records are still being continued, a very reliable index was obtained from 1911 to the present date. Before 1911 the number of these standard records falls off, and a variable selection of records was used to give the index, the extra records introduced being suitably compared with standard ones. For the earliest years every available record was employed, but it was not possible to relate many of these even indirectly to the standard epoch. In such cases the average over the whole of any early record was taken as 100 per cent; thereby fluctuations from year to year would be shown satisfactorily, but any secular trend would tend to be masked.

Rainfall history commenced in 1852 with a single record and for the next year there were four records. From 1863 there were at least four records for each island. A great expansion took place in the nineties and the total number of records as incorporated in the index reached 50 in 1893 and had increased to 108 by 1911. Indices for the years prior to 1863 should be regarded as crude approximations suffering from the limitations of the observational data, and their values do not enter directly into later calculations; from 1863 until about 1890 the indices must be accepted with some reserve. In fact, the discovery of a secular decline at a rate greater than that anticipated indicated that the reduction of early records to epoch produced consistently low indices. The secular trend will be discussed in a later section, but it will be convenient to mention the suggested adjustment to the indices:

To North Island Index add 2 for years up to 1880

1 for years from 1881 to 1889

To South Island Index add 2 for years up to 1871

1 for years from 1872 to 1884

The complete list of index figures as evaluated for the two islands separately and then combined for the whole Dominion is displayed in Table I.

TABLE I. LIST OF ANNUAL RAINFALL INDICES

Column A : Wolfer Sunspot Number
 Columns B : Rainfall Index
 Columns C : Smoothed Index
 Columns D : Residual

Year.	A.	New Zealand.			North Island.			South Island.		
		B.	C.	D.	B.	C.	D.	B.	C.	D.
1852	54	110	(110)	+ 0	—	—	—	110	(110)	+ 0
53	39	126	(126)	+ 0	108	(108)	+ 0	143	(143)	+ 0
54	21	110	121	-11	129	(129)	+ 0	90	143	-53
55	7	81	108	-27	82	128	-46	79	126	-47
56	4	95	96	- 1	86	117	-31	105	105	+ 0
57	23	92	90	+ 2	103	106	- 3	80	89	- 9
58	55	113	90	+23	132	100	+32	95	82	+13
59	94	63	93	-30	59	101	-42	66	84	-18
60	96	99	98	+ 1	109	107	+ 2	89	91	- 2
1861	77	123	105	+18	137	112	+25	109	100	+ 9
62	59	103	109	- 6	97	113	-16	108	107	+ 1
63	44	117	109	+ 8	115	108	+ 7	118	110	+ 8
64	47	98	105	- 7	100	100	+ 0	96	108	-12
65	30	105	101	+ 4	91	95	- 4	118	104	+14
66	16	93	99	- 6	91	94	- 3	95	102	- 7
67	7	99	100	- 1	103	96	+ 7	96	102	- 6
68	37	108	102	+ 6	99	99	+ 0	118	104	+14
69	74	99	103	- 4	102	101	+ 1	95	105	-10
70	139	102	102	+ 0	94	101	- 7	111	104	+ 7
1871	111	105	101	+ 4	112	101	+11	98	101	- 3
72	102	97	102	- 5	94	103	- 9	100	100	+ 0
73	66	105	104	+ 1	107	106	+ 1	103	102	+ 1
74	45	104	105	- 1	108	109	- 1	101	103	- 2
75	17	115	105	+10	118	109	+ 9	112	102	+10
76	11	95	104	- 9	99	106	- 7	91	102	-11
77	12	105	104	+ 1	109	104	+ 5	102	104	- 2
78	3	102	103	- 1	88	103	-15	116	104	+12
79	6	109	101	+ 8	120	102	+18	99	101	- 2
80	32	100	100	+ 0	104	103	+ 1	96	98	- 2
1881	54	85	101	-16	84	105	-21	85	97	-12
82	60	107	104	+ 3	109	107	+ 2	106	100	+ 6
83	64	118	106	+12	124	107	+17	113	104	+ 9
84	64	108	105	+ 3	108	104	+ 4	108	107	+ 1
85	52	85	103	-18	80	98	-18	91	110	-19
86	25	111	101	+10	97	94	+ 3	125	110	+15
87	13	104	98	+ 6	103	92	+11	104	105	- 1
88	7	97	93	+ 4	81	91	-10	112	97	+15
89	6	84	89	- 5	95	91	+ 4	72	89	-17
90	7	86	90	- 4	98	95	+ 3	74	86	-12
1891	36	86	96	-10	89	103	-14	82	90	- 8
92	73	113	105	+ 8	114	112	+ 2	111	98	+13
93	85	124	111	+13	135	116	+19	112	106	+ 6
94	78	101	112	-11	101	114	-13	102	111	- 9
95	64	113	108	+ 5	110	109	+ 1	117	110	+ 7
96	42	103	103	+ 0	101	105	- 5	106	104	+ 2
97	26	99	99	+ 0	114	103	+11	85	98	-13
98	27	93	99	- 6	91	103	-12	96	96	+ 0
99	12	105	101	+ 4	104	102	+ 2	106	98	+ 8
1900	10	105	101	+ 4	109	101	+ 8	101	99	+ 2

[Continued]

TABLE I. LIST OF ANNUAL RAINFALL INDICES

Column A : Wolfer Sunspot Number

Columns B : Rainfall Index

Columns C : Smoothed Index

Columns D : Residual

Year.	A.	New Zealand.			North Island.			South Island.		
		B.	C.	D.	B.	C.	D.	B.	C.	D.
1901	3	96	100	- 4	94	100	- 6	97	99	- 2
02	5	101	101	+ 0	99	102	- 3	102	100	+ 2
03	24	98	104	- 6	102	106	- 4	95	102	- 7
04	42	116	106	+10	122	110	+12	110	104	+ 6
05	64	108	105	+ 3	109	111	- 2	108	102	+ 6
06	54	94	104	-10	97	110	-13	91	97	- 6
07	62	108	102	+ 6	127	110	+17	89	94	- 5
08	49	98	101	- 3	99	109	-10	96	94	+ 2
09	44	105	102	+ 3	109	107	+ 2	102	97	+ 5
10	19	100	103	- 3	105	105	+ 0	94	101	- 7
1911	6	101	102	- 1	99	100	- 1	103	104	- 1
12	4	104	98	+ 6	102	93	+ 9	106	104	+ 2
13	1	99	93	+ 6	89	87	+ 2	109	100	+ 9
14	10	80	91	-11	72	87	-15	89	94	- 5
15	46	87	94	- 7	92	94	- 2	83	92	- 9
16	55	105	100	+ 5	113	104	+ 9	96	95	+ 1
17	104	114	105	+ 9	117	110	+ 7	110	100	+10
18	81	109	105	+ 4	115	106	+ 9	102	103	- 1
19	64	87	100	-13	73	99	-26	102	102	+ 0
20	39	105	95	+10	109	93	+16	100	99	+ 1
1921	25	92	94	- 2	85	92	- 7	99	97	+ 2
22	15	92	97	- 5	92	97	- 5	92	97	- 5
23	6	104	102	+ 2	104	104	+ 0	103	100	+ 3
24	17	112	106	+ 6	121	109	+12	103	105	- 2
25	44	103	108	- 5	99	110	-11	108	107	+ 1
26	64	110	109	+ 1	111	110	+ 1	110	106	+ 4
27	69	103	109	- 6	107	110	- 3	98	105	- 7
28	78	110	107	+ 3	114	107	+ 7	106	104	+ 2
29	65	105	101	+ 4	103	100	+ 3	107	100	+ 7
30	36	85	94	- 9	86	93	- 7	84	94	-10
1931	21	92	89	+ 3	89	88	+ 1	94	90	+ 4
32	11	88	89	- 1	87	87	+ 0	89	90	- 1
33	6	93	92	+ 1	94	92	+ 2	92	93	- 1
34	9	94	99	- 5	88	100	-12	100	99	+ 1
35	36	111	106	+ 5	122	107	+15	100	104	- 4
36	80	115	109	+ 6	113	110	+ 3	117	108	+ 9
37	114	92	108	-16	90	108	-18	94	109	-15
38	110	122	105	+17	127	105	+22	117	106	+11
39	89	87	101	-14	88	102	-14	86	103	-17
40	68	100	100	+ 0	98	101	- 3	102	100	+ 2
1941	48	110	101	+ 9	111	101	+10	108	100	+ 8
42	31	99	103	- 4	96	102	- 6	101	102	- 1
43	16	100	105	- 5	102	103	- 1	98	107	- 9
44	10	114	109	+ 5	111	105	+ 6	117	113	+ 4
45	33	110	112	- 2	97	108	-11	124	114	+10
46	93	108	(108)	+ 0	109	(109)	+ 0	107	(107)	+ 0
47	(156)	96	(96)	+ 0	101	(101)	+ 0	91	(91)	+ 0

FREQUENCY

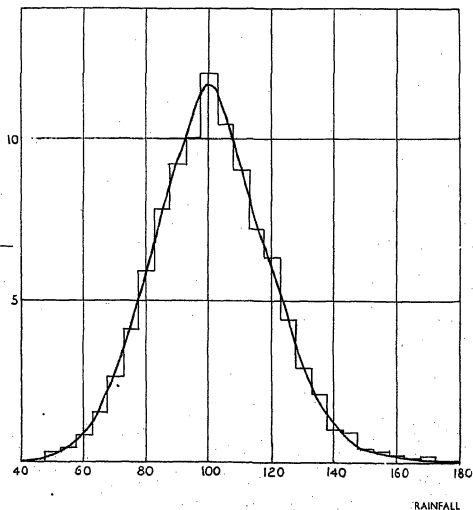


FIG. 1. Percentage Frequency Distribution of Annual Rainfall amongst New Zealand stations.

TABLE II. RELATIVE FREQUENCY OF ANNUAL RAINFALL AT NEW ZEALAND STATIONS
(Total frequency reduced to 100)

Rainfall centered at	50 or less	55	60	65	70	75	80	85	90	95	100	105	110
Frequency	0.3	0.4	0.8	1.5	2.6	4.1	5.9	7.8	9.2	10.0	12.0	10.4	9.0

Rainfall centered at	115	120	125	130	135	140	145	150	155	160	165	170 +
Frequency	7.2	6.3	4.4	2.9	2.1	1.0	0.9	0.4	0.3	0.2	0.1	0.2

DISPERSION OF RAINFALL

From the various stations and for the years from 1901 to 1947, there were 4,821 annual rainfalls considered in deriving the indices, and these had the frequency distribution indicated in Table II and illustrated in Fig. 1. Throughout this paper any annual rainfall is quoted as a percentage of the mean amount for the period 1911 to 1940 (which happened to be one of the drier 30-year periods).

The mean stands at 101.2 and the standard deviation is 19. There is a slight positive skewness, a feature which becomes more strongly pronounced in the distribution of monthly rainfall (Seelye 1946). As noted in an earlier study on variability of annual rainfall (1940), occurrences of rainfall outside the range 50 to 175 per cent are very rare and have been recorded only in a few low rainfall areas. It was shown also that the mean deviation of annual rainfall with few exceptions ranged from 10 to 20 per cent, or what is equivalent, seeing that the general distribution is not markedly different from a normal one, the standard deviation is 12 to 25 per cent depending on locality.

Now, in the case of temperature, a warm year generally implies that all parts of the country are warmer than normal, but in the case of rainfall there is a greater diversity so that a generally wet year as indicated by a high index is almost certain to have some areas with deficient rainfall. A similar observation holds for departures from normal in the reverse direction.

At the majority of stations the rainfall fluctuations from year to year referred to above have standard deviations between 15 and 20 per cent, varying with their situations. On the other hand, considering the dispersion of rainfall amongst the stations throughout the country, the standard deviation is for the majority of years from 14 to 19 per cent. The most uniform distribution of rainfall in terms of percentage for normal occurred in 1863 when the standard deviation was only 9 per cent, but only eight stations were involved. Several years since then have had the next lowest figure of 12 per cent. For greatest diversity of rainfall departure from normal, 1878 with a standard deviation of 33 per cent is remarkable. Strongly developed westerly situations appear to have prevailed, conditions remaining very dry in Hawkes Bay and Canterbury and exceptionally wet in the Southern Alps, Westland and Southland, and in September of that year memorable floods occurred in the rivers rising in these regions. The dispersion was next highest in 1907 with a standard deviation of 25 per cent, that year being particularly wet over the Auckland Province and fairly dry in Canterbury, Otago and Southland. The standard deviation in any year may be high or low irrespective of whether the year as a whole is wet or dry.

It should be noted that when deduced from 100 typical stations, the annual index representative of the whole Dominion will have a standard error usually of about one or two per cent.

As regards the index figures from year to year, these show a standard deviation of 12, 11 and 9 per cent for the North Island, South Island and New Zealand respectively. The North and South Island

indices therefore show much the same variability as the rainfall at the localities within the two islands where the rainfall is most reliable, and in taking an index over the whole Dominion a further slight reduction in variability is achieved.

ANNUAL RAINFALL FLUCTUATIONS

Extremes

The following extreme years may be mentioned. The wettest years for the Dominion as a whole were 1853 with rainfall of 126 per cent (approx.) which was wettest in the South; 1861 with 123 per cent (approx.), the wetness being fairly general, Southland excepted; 1893 with 124 per cent, especially wet in Auckland and Nelson; and 1938 with 122 per cent, the most noticeable excesses occurring in eastern districts between Oamaru and Whangarei. The driest years were 1855 with rainfall of approximately 81 per cent and 1859 with 63 per cent, then 1881, 1885 and 1930 each with 85 per cent and 1914 with 80 per cent. The last mentioned is the worst drought year since the sixties but dry conditions in 1859, even though its index is based on four records only, viz. Auckland 59, Heathcote Valley 57, Dunedin 88, and Invercargill 53 per cent, must have been at least as severe and probably more widespread than in 1914. Maps depicting deviations of rainfall from normal are included in Kidson's discussion (1931) on the four dry years 1914, 1915, 1919 and 1930.

Analysis

The fluctuations from year to year, if graphed, present a very irregular picture. Their examination is facilitated if they can be separated into longer and shorter periods by obtaining a series of smoothed annual indices and noting the residuals respectively. The method of smoothing selected was that described by Bullen (1938), who used Auckland City rainfalls as an example. Briefly, the method involves reduction of an index by $1/12$ (or more precisely $3/35$) of its fourth order difference, and this process which is symbolically

$$(y_n - \frac{1}{12} \delta_4 y_n)$$

is repeated until the fourth differences in the revised series become negligible, thus implying that between five successive smoothed indices there remains no more than one point of inflexion. The smoothed figures appear in column C of Table I, the residuals in column D, so that the actual rainfall index in column B is the sum of the entries in columns C and D. The two components will be discussed separately.

THE LONG-PERIOD AND SUNSPOTS

As can be seen from inspection of Fig. 2, the smoothed figures correlate closely with the Wolfer sunspot numbers which are included in the first table. Correlation coefficients between annual rainfall (unsmoothed and smoothed) and sunspot numbers calculated for the 83 years 1863 to 1945 inclusive, are shown in Table III.

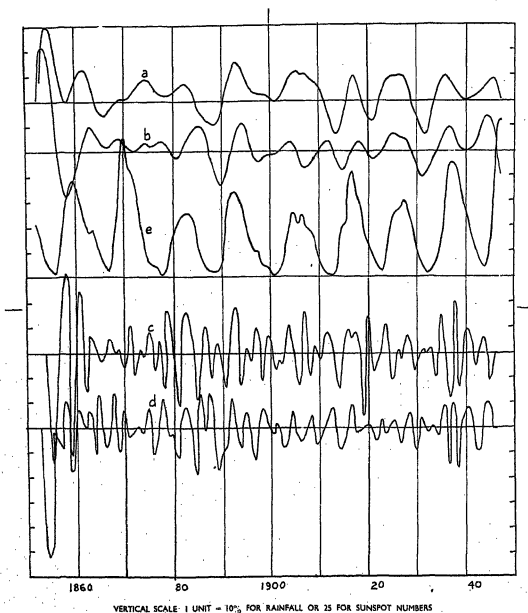


Fig. 2. Fluctuations of Annual Rainfall resolved into (a, b) longer and (c, d) shorter period components for the North and South Islands and (e) annual sunspot numbers.

TABLE III. COEFFICIENTS OF CORRELATION BETWEEN RAINFALL AND SUNSPOT NUMBERS

	Unsmoothed Rainfall	Smoothed Rainfall
North Island	+ 0.27	+ 0.47
South Island	+ 0.16	+ 0.31
New Zealand	+ 0.28	+ 0.42

The smoothed data show a much closer correlation than the unsmoothed, and the North Island than the South. This is in general accord with the results of Kidson (1928), who gave the correlation coefficients for numerous individual records with sunspots, but the

majority of these values were less than those obtained in this paper from the composite rainfall indices for the islands concerned.

Sunspot minima occurred in 1856, 1867, 1878, 1889, 1901, 1913, 1923, 1933 and 1944. The average period is 11 years but to make allowance for the two intervals of 12 years followed by another two of 10 years, these intervals were reduced and extended respectively in direct proportion to the average of 11 years. Treating rainfall and sunspots, averaging over seven complete cycles 1867 to 1943 and making an acyclic correction in the customary manner, results are obtained as set out in Table IV and graphed in Fig. 3.

TABLE IV. AVERAGE RAINFALL OVER AN 11-YEAR SUNSPOT CYCLE

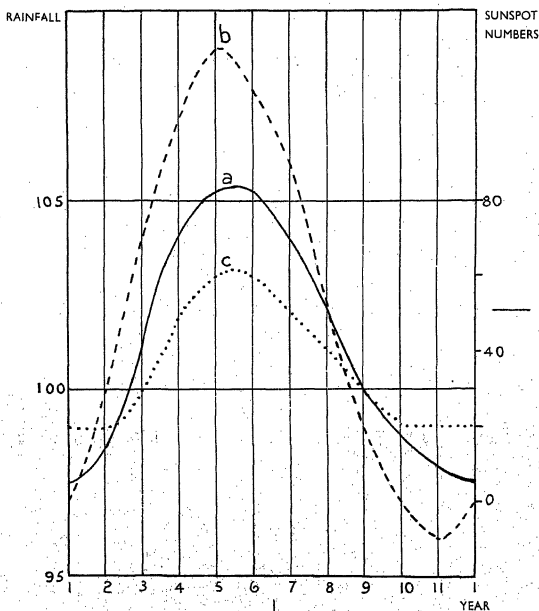


FIG. 3. Average 11-year Sunspot Cycle. (a) Sunspot numbers; smoothed rainfall for (b) North Island and (c) South Island.

TABLE IV. AVERAGE RAINFALL OVER AN 11-YEAR SUNSPOT CYCLE

Year	1	2	3	4	5	6	7	8	9	10	11
Sunspot No.	5	14	42	73	83	82	67	50	30	17	10
North Is Smoothed	97	100	104	107	109	108	105	102	99	97	99
South Is. ..	99	99	100	102	103	103	102	101	100	99	99
New Zealand ..	98	99	102	105	106	106	103	101	99	98	97
North Is. Unsmoothed	96	100	103	107	107	113	103	97	102	96	97
South Is. ..	99	100	96	106	103	105	101	98	102	98	99
New Zealand ..	98	100	100	106	106	109	102	97	102	97	98

Thus the long period fluctuation contains in the average cycle a variation over the range of 13 and 4 per cent for the North Island and South Island respectively, and this goes closely in phase with the number of sunspots. If unsmoothed indices are used, as in the latter portion of the table, irregularities would be superposed on these graphs which idealize the cycle, but the number of sunspot cycles available for study is too small when account is taken of the variability of rainfall for the values of such smaller fluctuations to be accepted as significant. In the course of an actual sunspot cycle more rapid fluctuations of various lengths but averaging three years are to be expected. These will now be examined.

THE THREE-YEAR PERIOD

The residual rainfall has an average period which can be evaluated after noting the times the quantities in column D or the corresponding graph in Fig. 2 experience similar changes in sign. The average time interval between successive up-crossings gives the period, and the values found were 3.1 years for the North Island and 3.0 years for the South. In deriving the former two oscillations touching the axis and one very small oscillation were ignored. The New Zealand data lead to 2.8 years or 3.0 years according as three small movements near the axis of the graph are included or not. The separate intervals vary appreciably in length and the fluctuations show a considerable variation in their amplitude. The average ranges of this short period fluctuation are 21 per cent, 17 per cent and 15 per cent for North Island, South Island and New Zealand respectively, these figures being averages of the range found for each complete oscillation. Similar values for the long period fluctuation are rather smaller, namely 17 per cent, 13 per cent and 13 per cent respectively.

Other determinations of approximately three-year periods may be mentioned; a 3.2-year period in rainfall for North Auckland Peninsula and a 3.3-year period for temperatures in Wellington. Bullen (1938) found a 3.5-year period for Auckland City rainfall.

Kidson (1925) studied variations over a three-year cycle in several features in Australian weather as well as in pressure in various parts of the world. His analyses were based on means taken over exactly three calendar years, so that fluctuations in the period itself would

lead to an average cycle very much reduced in amplitude in all cases where the period was an irregular as in New Zealand rainfall. One irregularity was compensated for by omitting entirely certain pairs of years in which this cycle was assumed to be inoperative, there being no evidence of it in the series of Darwin pressures in which a three-year cycle is normally strongly established. Kidson further observed that the Australian continent and Samoa exhibited this cycle with opposing phases and that New Zealand, being near the dividing position, would not expect to have the three-year effects very fully developed, and offered evidence of an 18-month component which was slight near the tropics but which became the predominant feature in the cycle for the more southern localities of the Australasian region.

From close examination of the present data it is found that the short period oscillations for the North and South Islands agree intermittently in their phase. This state of affairs recurs near sunspot maximum and endured over the actual year of maximum in five of the cycles, but in two others set in the year after maximum and in the case of the 1870 maximum not till the third year thereafter. In the intervening periods the disagreement between the fluctuations for the two islands appears to be a result not so much of phase shift but rather of temporary variations of the period. Even during the occasions when the two fluctuations are similar their periods were variously from two to four years.

SECULAR TREND

Hitherto, it has been customary to assert that there is no evidence of any secular trend in meteorological elements which have been systematically observed in New Zealand. Having the present indices, a return is made to this problem to see whether rainfall exhibits any general tendency to decline. Computing a linear trend is equivalent to finding the gradient of the straight line which fits the series of rainfall indices best in that the sum of squares of departures of the actual values from this line shall be as small as possible. In Table V are the results of this calculation when applied to the rainfall indices for the years from 1863 to 1947 and to their smoothed versions for the years from 1863 to 1945. As a result of the smoothing process, records prior to 1863 enter indirectly into the values of the period used.

TABLE V. AVERAGE RAINFALL TREND IN PERCENTAGE DECLINE PER ANNUM

	Unsmoothed	Smoothed
North Island	0.010 ± 0.06	0.004 ± 0.03
South Island	0.018 ± 0.05	0.009 ± 0.02
New Zealand	0.012 ± 0.04	0.004 ± 0.02

Fluctuations for individual years about the trend line are so large that the standard errors for the rates are much greater than the rates themselves, so that this evidence of a general decline is inconclusive.

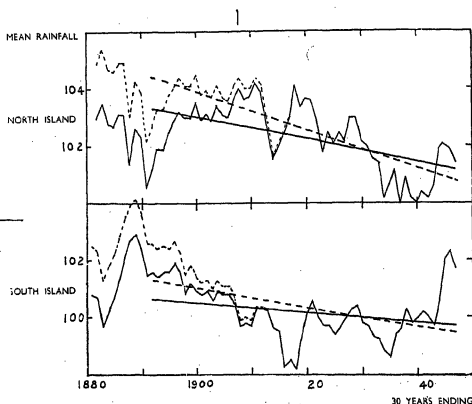


FIG. 4. Running 30-year means for (a) North Island and (b) South Island linear trends. Dotted portions show results of revising indices for years prior to 1890.

If length is sacrificed in this series by taking running 30-year means, a smoother variation is obtained as shown in Fig. 4, and a line can now be fitted to the means for the 30 years centred at the beginning of the years 1878 to 1933 inclusive. The standard errors of the determinations are much reduced and results of significance obtained as set out in Table VI.

TABLE VI. AVERAGE RAINFALL TREND IN PERCENTAGE DECLINE PER ANNUM
(From running 30-year means)

	Unsmoothed	Smoothed
North Island	0.043 ± 0.008	0.041 ± 0.008
South Island	0.018 ± 0.007	0.021 ± 0.007
New Zealand	0.025 ± 0.006	0.021 ± 0.005

Thus, by considering the past 85 years and giving less weight to the 15 years beginning and ending the series as is inevitable in taking running means, there is good evidence of a decline at the rate of at least four per cent per century in the North Island and two per cent in the South Island.

In using isolated records for the early indices it was tacitly assumed that there was no secular trend. Now that a trend has been established

it becomes clear that before 1890 the indices will tend to be consistently low. To overcome this defect it was assumed that a record should be compared with the general run of the indices for the appropriate island in those cases where comparison cannot be made with a standard record. This should remove any systematic error. The adjustments recommended of one or two per cent to years before 1890 have already been mentioned with the presentation of Table I. After revision of the 30-year means as shown in the raised portion of the graphs in Fig. 4, the linear trends were recalculated as follows:

TABLE VII. REVISED TRENDS—PERCENTAGE DECLINE PER ANNUM

North Island	0.067
South Island	0.033
New Zealand	0.050

Of course the description of the slow movements of the rainfall as a linear trend is an over-simplification, for even with the 30-year means there are considerable variations. There is no basis for deciding whether an average linear trend is likely to be a persistent feature or whether rainfall is in the process of undergoing some large scale oscillation with the prospect of many years of increasing rainfall ahead. The graphs do show some recovery in the most recent period, more strongly for the South Island than for the North, but how permanent this recovery is must remain an open question in the meantime.

There is no special virtue in using 30 years as the period for the running means but such an interval is commonly used in presenting climatological data. An interval of 33 years embracing exactly three sunspot cycles of average length should give slightly smoother variations but the variability of the sunspot cycle makes this advantage too small to justify the use of a 33-year period in place of the convenient 30-year period.

From the revised indices from 1863 to date, the highest and lowest 30-year means are shown in Table VIII:

TABLE VIII. EXTREME 30-YEAR MEANS OF RAINFALL

	Highest		Lowest	
	Mean Rainfall	Period Ending	Mean Rainfall	Period Ending
North Island	104.5	1900	100.0	1937, 1940
South Island	102.7	1896	98.2	1918
New Zealand	103.3	1896	99.6	1934

LONG RANGE FORECASTING

As the three-year period can outweigh the rainfall variation progressing in harmony with the sunspot numbers, some more definite order in the apparent irregularities of the former requires to be discovered before a reasonable basis can be established for developing long-range forecasting.

Kidson's comprehensive survey of the three-year cycle merits extension and also revision and elaboration if it can be shown that the variation in periodicity about an average of some three years is a real and systematic feature, not only of rainfall but of other meteorological elements as observed in the South Pacific region.

ACKNOWLEDGMENT

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CORNISH STONE AND FELDSPAR IN NEW ZEALAND

By J. HENDERSON

Summary

Cornish stone has long been indispensable to the potter. It consists essentially of feldspar and quartz, but some consider that its place in the ceramic industry can advantageously be taken by feldspar, which is more uniform in composition. The original Cornish stone is a granite, rich in feldspar partly decomposed to kaolinite, and containing a small amount of fluorspar. For use in white ware the Fe_2O_3 content should not be above 0.5 per cent. The sum of the alkalis should exceed 10 per cent, the lime content should be less than one per cent, and up to 10 per cent of free quartz seems to be generally acceptable.

Likely sources of high-grade stone are the granites, pegmatites and aplites of Nelson, Westland, Otago and Stewart Island, and the rhyolitic and trachytic volcanic and dyke rocks of North Auckland, Hauraki-Rotorua, Canterbury and the Dunedin district.

INTRODUCTION

THE early Egyptians, who made the oldest dated pottery, attributed its invention to the gods. At first their vessels were soft and porous and held together by the bond developed when the kaolinite of clay loses its water by heat, but later the Egyptians used a glaze of rich turquoise blue made with alkali, probably the "natron" of the soda lakes of Egypt. The term "porcelain" designates pottery to which firing has imparted incipient vitrification and, with vitrification, translucency. This, the highest quality of pottery, originated in China where it is made from a mixture of kaolin and granite or kaolin and pegmatite. The mineral that gives ordinary clay its properties is kaolinite, a decomposition product of the feldspars. Commercial kaolin consists largely of kaolinite sufficiently low in iron-bearing impurities to burn white or nearly white. Kaolin melts at a very high temperature and the vitrification to which the porcelain owes its properties is due to the feldspar added to the ware in the form of granite or pegmatite. This the Chinese call "petuntse"; in Europe the potters term it "Cornish stone", "China stone", "moorstone", "growan stone" or "grawen." Cornish stone has long been indispensable to the potter. It consists essentially of feldspar and quartz, but some consider that its place can be advantageously taken by feldspar which is more uniform in composition.

The bodies of porcelain and earthenware consist essentially of materials resistant to heat, together with others that melt in the kilns and bond the whole. The common refractory materials are kaolinite, silica, bone ash and talc, and the fluxing material is feldspar alone or mixed with substances still more fusible. The proportion of feldspar in the body mixture usually ranges from 10 to 30 per cent, the amount depending on the temperature of firing and the purpose for which the article is designed. Some dental porcelain contains as much as 80 per cent. If too much feldspar is present the article may lose its shape in the kiln; if, on the other hand, there is too little, it may be unduly porous or insufficiently strong. All ware except the porcelains are porous and absorbent unless they are glazed. Usually the

“biscuit” is dipped in, or painted with a liquid containing finely divided feldspar and other fluxes in suspension, and then reheated to melt the glaze so that the impervious coating is formed.

Igneous rocks generally consist of about 60 per cent of feldspar, which also forms a substantial proportion of many sedimentary and metamorphic rocks. Some igneous rocks consist almost entirely of feldspar, and in others the mineral crystallizes out so coarsely that it may be separated out by cobbing. Again some rocks consist largely of feldspar and quartz and, if the proportion of iron-bearing minerals, objectionable to potters because they discolour the ware, is sufficiently low, such rocks are used as a source of feldspar, the proportion of silica added to the body mixture being reduced to allow for the quartz in the rock. Such rock is termed “Cornish stone” from a deposit in Cornwall used by potters. The original Cornish stone is a granite rich in feldspar partly decomposed to kaolinite and containing a small amount of fluor spar; such material is softer and more easily pulverized than completely unaltered rock. The analysis of a commercial Cornish stone quoted (No. 1 of Table I) shows a content of 0.5 per cent of Fe_2O_3 , an amount that should not be exceeded for Cornish stone used for white ware. More than one per cent of Fe_2O_3 in the flux will yield a product altogether too dark. Few rocks are sufficiently low in iron-bearing minerals to be suitable for white ware. These minerals are mentioned below as the impurities of feldspars; and, as some can readily be removed by magnetic extraction, granites and other rocks of similar composition are included in this account, provided the iron content, expressed as Fe_2O_3 , does not greatly exceed 1 per cent, in the expectation that in some at least of the rocks, the iron content could be reduced enough to make the rock usable.

Atmospheric weathering or volcanic emanations may in part decompose a feldspar-bearing rock and cause it to disintegrate. Water may transport the detritus, sort it, and lay down beds of different textures and compositions. Some of such sedimentary deposits may have value as sources of feldspar.

Feldspars are compound silicates of alumina, the alkalis and the alkaline earths. The common ones contain potash (orthoclase), soda (albite), or lime (anorthite). Small amounts of other related elements are likely to be present; pure minerals are rare. The soda and lime feldspar forms a continuous series ranging from albite ($\text{Na}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$) to anorthite ($\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2$), through oligoclase (Ab6-3An1), andesine (Ab3-1An1) labradorite (Ab1An1-3) to bytownite (Ab1An3-6). These are the plagioclases, which crystallize in the triclinic system, whereas orthoclase ($\text{K}_2\text{O} \cdot \text{Al}_2\text{O}_3 \cdot 6\text{SiO}_2$) is monoclinic. Feldspars of two mineral species are often intergrown, commonly potash, with soda or with the plagioclase members, but not potash with lime feldspars.

The physical properties of the feldspars are similar. The several minerals have about the same hardness (6 to 6.5) and good cleavage in two directions. The fracture is uneven, the colours are white, cream, pale grey, greenish, etc.; orthoclase is commonly pink. The streak is

white and the lustre pearly to vitreous. The specific gravity of orthoclase is 2.57, of albite 2.63, and of anorthite 2.75. The melting points are respectively 1,200°C, 1,100°C and 1,530°C.

The chief accessory minerals with commercial feldspars, either included in the crystals or bonded to them, are quartz, muscovite, biotite, garnet, beryl, tourmaline, the ferromagnesian minerals (augite and hornblende) and the iron ores (magnetite, ilmenite and haematite). The common decomposition products of the feldspars themselves are quartz, sericite, kaolinite and zoisite; these affect the fusibility of the feldspars, but in small amount are not objectionable. The iron-bearing accessories (biotite, garnet, tourmaline, ferromagnesian, iron ores and their decomposition products) are positively deleterious in that they tend to discolour the ware. As far as practicable these minerals should be reduced by selection of material and by magnetic extraction.

In Europe and America there are market grades for the feldspar, though these are difficult to define and maintain owing to the irregularity of the deposits and the inconstancy of the mixture of feldspar minerals even in the same deposit. The sum of the alkalis in an analysis should exceed 10 per cent, the lime should be less than 1 per cent, and up to 10 per cent of free quartz seems to be generally acceptable, though some American potters require under 5 per cent. The second grade should not contain over 25 per cent of free quartz, an amount very little less than the average in alkali-granite or in Cornish stone. The feldspar should be sufficiently free from iron, i.e., containing say 0.1 per cent of Fe_2O_3 to melt to a clear white or slightly tinted colour, with dark specks due to particles of iron-bearing minerals. In pottery bodies high-potash feldspars are preferred, whereas for glazes the more fusible soda mineral is used. In glass making, feldspar is primarily a source of alumina, so that the more aluminous lime feldspars are probably suitable, and free quartz is undesirable.

GRANITES AND PEGMATITES

In New Zealand granites and pegmatites occur *in situ* only in the South Island. They cover many hundreds of square miles in West Nelson extend in patches in front of the Alps through Westland, and are abundant in West Otago and Stewart Island.

Granite is a rock made up of crystals of quartz, feldspar, and mica, with sundry other minerals in minor amount. The crystals and grains, though readily distinguishable, are not, in general, so large for it to be practicable to break the rock and pick out by hand large quantities of a particular mineral. The pegmatites are exceptionally coarse-grained rocks that usually form veins and irregular masses in granite, or in rocks adjacent to granite. They are considered to be formed from the last part of a granitic magma to crystallize. Some consist chiefly of quartz, in others feldspar predominates, and in still others these minerals seem to have crystallized at the same time so that the quartz occurs in disconnected but optically continuous patches in the feldspar as prisms and wedges with angles of 60°, recalling

cuneiform writing and giving rise to "graphic" structure. Orthoclase and quartz in graphic intergrowth consist of a mixture of 72.5 per cent of the former and 27.5 per cent of the latter.

West Nelson Granites

Granite in West Nelson is exposed over an area of more than 2,000 square miles. The rock forms much of the mass of the highlands and is disposed in three meridionally-trending belts. The most easterly belt extends south from Separation Point to Mount Murchison, a distance of over 70 miles and averages at least 5 miles across. It forms the front ranges of the highland overlooking the Nelson lowlands from the west and is probably the most readily accessible granite in New Zealand. In Wellington the Post Office and Public Trust buildings are faced with stone from Tonga Island which lies in Tasman Bay and is part of this granite belt. The belt next to the west is larger, extending from Kahurangi Point to Ahaura River, a distance of 120 miles, and averaging about 12 miles across. The west belt forms the coastal range between Greymouth and Westport and extends north in isolated patches to Kongahu Point.

The granite of the eastern belt is not only the most accessible but in general it also seems to be less firmly bonded than the rocks of the central and western belts. This allows of deeper weathering and suggests the possibility of obtaining suitable material by washing the kaolin or other commercial products from the decomposed rock. Some tests to this end have already been carried out (see below).

Half a dozen analyses of rock samples from places far apart on the Separation Point—Mount Murchison granite belt are available. In all samples soda is about 50 per cent higher than potash, and the iron content, expressed as Fe_2O_3 , ranges up to 2.4 per cent and averages about 1.4 per cent. The analysis quoted by Taylor (1943) of a sample from Tonga Island is considered typical of the normal rock. It contains 1.36 per cent of Fe_2O_3 an amount that magnetic extraction after grinding would probably considerably reduce. An analysis of a sample from Pearse Stream is quoted (No. 2, Table I); another sample from Brewery Creek, a branch of Owen River, contains only 0.69 per cent of Fe_2O_3 (No. 3, Table I).

On the other hand the seven samples analysed from the great rock bodies of the central and western granite belts of West Nelson show Fe_2O_3 contents averaging 4.5 per cent and ranging up to 6 per cent. In these rocks the potash is equal to, or decidedly greater than the soda (Morgan and Bartrum, 1915, pp. 105-6; Henderson, 1917, pp. 109-10). Some of these rocks might perhaps be classed as granodiorites; none contains as small an amount of Fe_2O_3 as does the richest iron-bearing granite from the eastern belt. According to G. W. Tyrrell (1926), the average Fe_2O_3 content of 19 typical granites is 3.5 per cent.

In places the granite of the eastern belt is decidedly porphyritic and there are large masses of the rock in which crystals up to 4 inches long of pale-pink orthoclase form a substantial proportion. Mr T. J. McKee, of Mapua, in a letter dated 6 March, 1945, writes, "A possible

source of feldspar may be the partly decomposed granite along the coast [of Tasman Bay] from Riwaka . . . to Separation Point. Where the rock is porphyritic, crystals of feldspar could be separated by screening the weathered granite after quarrying. I am sending a sample of crystals from a road cutting about one-and-a-half miles west of Ngaio Bay, north of Kaiteriteri. Here the granite is very weathered and friable.

"In places crystals would compose about 50 per cent of the rock. They could be cleaned by washing and 'rumbling' to wear off the soft material. I notice, though, that there are inclusions of iron-bearing minerals. . . I think there are commercial quantities of feldspar crystals in the weathered granite."

The sample of crystals had fragments of the rock matrix attached and where broken across showed regular zonings of inclusions. They were examined in the Dominion Laboratory and the analyst reported that the sample (L. 509)* contained 11.20 per cent of potash and 2.95 per cent of soda. Lime was either absent or occurred in only very small amount. If all the alkalis are present as feldspar, which is practically certain, the sample contained 93 per cent of alkali feldspar. The iron present was equivalent to 0.75 per cent of ferric oxide. The analyst states that, when fused at about 1,250°C, a light-grey glass speckled with reddish brown to black specks was formed. These specks were due to particles of iron ore which could largely be removed by magnetic extraction. The colour would then be satisfactory for pottery.

In Cornwall, Devon, and North Carolina, decomposed granite is washed in large amount and the fine fraction, consisting chiefly of kaolinite, is sold as commercial kaolin. Fragmental mica is also separated out. As already noted the granite of the eastern belt has been deeply attacked by weathering agents and in places is readily friable for 20 feet or more from the surface. In zones of crushing or stress this depth is no doubt much greater. The decomposition is not everywhere due to the present cycle of erosion for, where depositional contacts of Tertiary strata and the granite are exposed, the underlying rock is deeply altered and crumbles readily in the hand. This applies also to the rocks of the western belt, and in parts of the Westport Coalfield it is not easy to say within a few feet where, in a blended unconformity, the Eocene coal-measure grits end and the gneiss begins.

B. L. Taylor (1943) prospected and sampled masses of decomposed granite near the Baton Saddle on the edge of the high country 30 miles west of Nelson. Here the deeply altered rock is traversed by many shear planes and is also overlain by strata of middle Tertiary age. The samples tested yielded on washing about 30 per cent of material fine enough to be classed as clay. This consisted of from 35 to 65 per cent of alkali feldspar, the other constituents being chiefly quartz and kaolinite. Unfortunately, except for one sample from a well-weathered outcrop, these feldspathic clays yielded fused products far too dark to be of use in potteries.

* L. 509 is the reference number of the sample in the Dominion Laboratory, Wellington.

Mr T. J. McKee lately has forwarded samples from other localities in the district where decomposed outcrops of the same granite are exposed. The first is from the Waihero Valley, a mile and a half south of Pangatotara; here weathered granite shows for a few feet above the water channel along the road for many chains and apparently extends into the hillside, being covered only with soil. The second sample is from sideling cuttings on the same Lower Moutere—Ngatimoti Road from the church down to the flats of Orinoco Stream, a distance of 50 chains. The third sample is from alluvial [(?) residual] sand and clay resting on granite exposed along the Orinoco—Neudorf Road 5 chains from the Thorpe—Ngatimoti Road. Two other samples were obtained from Mr C. Boyd's property in the Sherry Valley, 4 miles south from Matariki Post Office. McKee separated the clay fraction, made up of particles less than 0.01 mm across, from all but the first, which was washed in the Dominion Laboratory through a 300 mesh British standard sieve. The results of the laboratory tests are shown in Table I, together with those of the Baton granites forwarded by B. L. Taylor. The clay fractions, calcined at 1,150°C, yielded products as follows:—

- (1) Completely vitrified with tendency to soften. Uniform light grey. Very fusible.
- (2) Vitrified, tending to soften. Light cream with some specks.
- (3) Vitrified, edges sharp. Light brown, numerous dark specks.
- (4) Completely vitrified and softened at edges. Greyish-white with minute dark specks. Very fusible.
- (5) Vitrified, edges sharp. Biscuit brown.
- (6) Completely vitrified, beginning to soften. Brown.
- (7) Very hard, incipient vitrification. Pinkish grey.
- (8) Very hard, incipient vitrification. Pinkish grey.

The analyst comments on the samples No. 1 to No. 5. No. 1 he considers should be useful as a feldspathic flux for porcelain insulators and Nos. 2 and 4, with more careful washing, would probably have value for the same purpose.

The samples are clay or fine silt, in the sense that the bulk of the particles are very small though they consist chiefly of feldspar and quartz and of kaolinite and 40 per cent of feldspar, including over 10 table, which is comparable in its content of alkali metals with samples No. 1 to No. 5, of which Taylor (1943, p. 86) quotes a complete analysis, had a theoretical mineral composition of about 24 per cent each of quartz and of kaolinite and 40 per cent of feldspar, including over 10 per cent of lime feldspar present also without doubt in samples No. 1 to No. 5. Dr Hutton examined samples No. 2 to No. 4 under the microscope and reports that feldspar and quartz make up the bulk of each. The feldspars are partly kaolinitized and some kaolinite is present. The accessories are similar in quantity and composition to those in the Baton granite (Taylor, 1943, p. 84).

In the central and western belts, outcrops of decomposed granite from which there is some prospect of obtaining commercial feldspar or Cornish stone by washing, are not known. The gneiss and granite

of the Charleston area were deeply weathered before the deposition of the Tertiary strata in that district, the former to a biotitic clay and the latter to a good-grade kaolinite with grains of quartz.

West Nelson Pegmatites and Aplites

Dykes of light-coloured igneous rock occasionally transect outcrops of granite or the sedimentary rocks intruded by them. These are two kinds, coarse-grained, termed pegmatites, and, less common, fine-grained, known as aplites. Both in a general way correspond in mineral and chemical composition to their parent rock-body, though usually they are richer in alkali feldspar and quartz minerals that tend to crystallize late. Both rocks are thought to be products of the solidification of the magmatic residue squeezed by earth pressure from the partly crystallized rock mass now forming the granite body. The pegmatites were rich in water and other volatiles that made for great fluidity and slow crystallization at comparatively low temperatures, so that the veins may be thin, branched, grade into the wall rock, and contain large crystals and mineral aggregates. The fine even grain of the aplites and their sharply defined contacts suggest small amounts of volatile constituents, quicker cooling and less mobility.

In the Baton district a large dyke of undecomposed pegmatite exposed in a cutting on the road between 3 and 4 miles from the junction of the Baton with the Motneka has been quarried for use as Cornish stone. In a hurried visit the width of the dyke was not established but it is at least half a chain across. The rock consists of a fairly coarse matrix of quartz, white feldspar and biotite containing numerous larger crystals of pink orthoclase. An incomplete analysis is given in Table I (No. 4) and from this, the rock theoretically contains 71 per cent of alkali feldspar together with 5 per cent of lime feldspar.

A fine even-grained granitic rock, probably aplite, though its boundaries were not observed, outcrops on the road up Dart River about a mile upstream from the Wangapeka. The analysis (No. 5, Table I) shows that the rock is about two-thirds feldspar and is quite low in Fe_2O_3 (1.08 per cent).

The usual acid dykes and veins crop out in the vast masses of the central granite belt of West Nelson but only one analysis of such a rock is available. This is of a sample from a small vein of micro-granite traversing porphyritic granite exposed on the fell fields of Mount Albert half a mile south-east from Trig. GA, which is 9 miles south-east from Reefton and in a hopelessly inaccessible locality. This is No. 6, Table I, and is quoted to show that dykes low enough in iron to be interesting to the potter may occur in the belt.

A very few analyses of acid dyke rocks connected with the granites of the western belt are available. One (No. 7, Table I) is that of a sample from a strong dyke of aplite traversing schistose greywacke on the old inland track from Seddonville to Karamaea about 100 chains north-east from Mount Kilmarnock. A second analysis (No. 8, Table I) is of a sample from a large mass of pegmatite, showing graphic structure and containing garnet, exposed in the upper valley of Otututu River. The locality, in the heart of the Paparoa Mountains, is highly inaccessible.

Gray gneiss and gneissic granite are the basement rocks of the Charleston district, on the coast 20 miles south of Westport. They form a plateau-like shelf of several square miles cliffed along the shore and disappearing inland toward the Paparoa Range under gently dipping Tertiary strata. Patches of coal measures, the lowest beds of the Tertiary sequence, occur on the shelf and there are also extensive deposits of young gravels and sands. Gneiss is continuously exposed only along the coast and the banks of the deeply entrenched streams. Its banding is well marked though somewhat irregular, and does not seem to influence the disposition of the numerous dykes of pegmatite. These appear to have no great lateral extent and are all very irregular both in course, dip, and thickness. Only the pegmatite dyke at the 'Old Mica Mine' (No. 9, Table I) and the one at Deep Creek are known to be in parts more than 10 feet thick, but smaller dykes up to 4 feet across are to be seen in most of the larger outcrops of gneiss.

The following description of the dyke at Deep Creek is quoted from an MS. report dated February 1945, by Mr H. W. Wellman. 'Deep Creek crosses the Westport-Greymouth Road three miles south of the site of the old town of Charleston and 20 miles south of Westport. The feldspar is contained in a pegmatite dyke about 70 feet above the stream and 30 chains east of the road. From the road to the dyke Deep Creek flows in a 100 feet gorge cut through Recent gravels covering the surface of the pakihi terrace, and is now well entrenched in the underlying gneiss. Immediately below the dyke is a dam which blocks the upper end of the gorge and forms a lake. The track to the dam follows the open pakihi along the edge of the gorge. The route is direct and, except for a sharp rise of about 30 feet from the road, almost level, but the surface of the pakihi is too swampy for wheeled vehicles and will have to be metalled before lorries can reach the deposits . . .

"The pegmatite dyke is exposed both in the face of the gorge and in a trench a chain long at terrace level. Outcrops in the gorge show that the dyke is about a chain wide; the north-west wall is exposed below an old pipe line and the south-east wall near the front of the trench. The downward limit is marked by a clear-cut horizontal contact in the face of the gorge 25 feet below the top of the terrace. Away from the gorge the extent of the dyke is not known, but the trench shows that it reaches back for at least a chain. The trench also shows that as much as 4 feet of Recent gravels overlie the dyke. These gravels do not increase in thickness away from the gorge and, by trenching, it should not be difficult to trace the dyke further. The volume of pegmatite rock at present proved by the trench and the gorge is not more than 3,000 cubic yards, which is equivalent to about 6,000 tons.

"The dyke is composed of quartz, feldspar and muscovite with an occasional 3-inch crystal of beryl. Quartz is the most common constituent and is in the form of large translucent blocks without crystal faces. Some of these blocks near the centre of the dyke are as much as 10 feet long. Mica forms about 10 per cent of the pegmatite but, though many of the mica crystals are 6 inches across, imperfections of various types make it quite impossible to obtain useful sheet mica from the deposit. It is not easy to estimate the proportion of recoverable feldspar, for although over 30 per cent of the rock was originally feldspar,

much has decomposed to kaolin, and much is finely intergrown with quartz. Some, perhaps 10 per cent of the body of the rock, is in the form of large unweathered crystals and a slightly larger proportion is only partly weathered.

“The weathering of the dyke is deep and does not appreciably decrease away from the original ground surface in the trench, consequently no abrupt improvement is likely if the trench is deepened. Discolourations due to iron oxide and conspicuous in the joint planes of the feldspar reduce the value of the deposit. Feldspar exposed in the face of the gorge and loose fragments sluiced down to the dam and exposed for about two years are relatively free of iron, a fact showing that prolonged weathering removes the iron.

To sum up: The Deep Creek deposit is well placed for easy working, for spoil can be dumped in the stream without difficulty and mining can be facilitated by an adequate water supply. Access is relatively good and the bulk of the rock is so soft that it can be worked without explosives. On the other hand only a small tonnage has been proved, almost all of which is badly iron stained.”

Westland Granites and Pegmatites

In North and South Westland mountains and hills of granite lie in front along the north-west margin of the Southern Alps from which they are separated by a great fault. They are thought to be the remnants of the southern extensions of the West Nelson granite belts in a foreland depressed by crustal stresses and partly overridden by the earth block that forms the Alps. Streams and glaciers from the main highlands have cut across the granite belts and divided them into several isolated masses, most of which are completely surrounded with alluvial deposits. Only one analysis of granite from North Westland is available. This is from the Mount Rangitoto mass, 8 miles south of Ross (Morgan, 1908, p. 135), it contains too much iron to be of use to potters. Pegmatites and aplites also occur in North Westland (*Ibid.*, p. 133) but no analysis of such rocks seems to have been made.

Hills of granite and of the intruded greywacke are common in South Westland though the area of the granite is not so large as that in North Westland (Wellman and Willett, 1942, map opp. p. 302). Acidic dykes traverse the intruded rocks west of the great fault and there is also, in the gneisses and schists east of the fault in the Blue River Section of the front highlands, an extensive zone of dykes and sills of pegmatites. Elsewhere in Westland neither dykes nor sills of acidic rock have been recorded east of the great fault. The only information on these deposits is from oral statements by Mr W. Heinz, manager of the mica mine which was worked in South Westland during 1944 and 1945, and from a short report by Mr H. W. Wellman of the Geological Survey who examined the mica deposits on two or three occasions. Mr Wellman reports as follows:—

“The feldspar forms a variable part of pegmatite dykes and sills associated with granitic intrusions. The dykes and sills extend for about a mile on either side of the Alpine Fault and intrude both

greywacke and schist. They cover a wide area but only those near either the road or the track have any present importance.

"The main road from Greymouth, Hokitika, and Ross ends a few miles beyond the bridge over the Paringa River and is continued by a 10 foot pack track. The distance of the bridge to the railhead at Ross, 100 miles, makes road transport prohibitive. From the bridge to the nearest possible shipping point, Bruce Bay, is eleven miles. The Bruce Bay timber mill closed because of shipping difficulties and since it ceased to cut timber a rapid deterioration of the shipping equipment has taken place, and it would be unwise to assume that anything could be shipped from Bruce Bay in the near future.

"The most accessible deposit shows in the bed of a small stream 10 chains south of the road and 14 chains west of the bridge over Paringa River. Two pegmatite dykes are exposed each about 10 feet wide and containing from 80 to 90 per cent of feldspar. They intrude jointed greywacke and are overlain with 10 feet of moraine, an overburden that makes it impossible to trace the deposit away from the creek and reduces the amount of cheaply producible feldspar to a few hundred tons at most.

"Similar pegmatite crops out beneath moraine farther west toward Lake Paringa, but is quite inaccessible. Crushed feldspar has been reported at two points in the same general locality a few chains from the track, but though searched for was not found. There is a good chance that a large deposit with little overburden may yet be found in the neighbourhood.

"Good feldspar occurs at the Mica Mine but all the deposits are at least 1,000 feet above the track and the cost of transport to the bridge would be prohibitive.

"Pegmatite dykes intruding greywacks are common on the track that follows the north bank of Blue River to the sea. These deposits are twelve miles by track from the Paringa bridge and well beyond the limits of economic transport. They lie on the route of the proposed extension of the Main South Road and are likely to be more accessible in the future. The dykes are irregular in thickness but there are large masses that contain as much as 70 per cent of feldspar.

"Doherty Creek, a small tributary of Blue River, flows north from the Paringa-Haast track a mile beyond the Mica Camp and the bridge. Its upper valley is in crushed greywacke and pegmatite pulverized along the Alpine Fault. Pegmatite exposed in a 20 foot cliff on the west side of the creek is largely composed of feldspar in part altered to kaolinite. Even when the Main South Road is extended this deposit will not be readily accessible."

According to Mr W. Heinz, feldspar occurred in masses up to many feet in length and some feet in width. To a depth of 6 feet or more from the surface the feldspar was weathered to a powdery mass, a sample of which examined by Mr A. Steiner, petrologist to the Geological Survey, was found to consist of kaolinite and particles of fresh oligoclase; particles of quartz and cloudy orthoclase were present in minor amount. No sample of the unweathered feldspar is available.

Granites and Pegmatites of Fiordland and Stewart Island

Several geologists have mapped and described the great masses of acid plutonic rocks about Chalky and Preservation inlets of Fiordland and forming the great part of Stewart Island. The few samples from the first group analysed are too high in iron to be of interest to the potter. There is a single analysis (No. 10, Table I) of a sample of granite from Stewart Island the "prevalent type . . . a white biotite-granite with over 77 per cent silica (Williams, 1934, p. 323 and Table III) that contains only 0.62 per cent of Fe_2O_3 . Samples from readily accessible exposures of granite in Stewart Island should be examined.

Dykes of pegmatite occur in the granite masses (*Ibid.*; A. McKay, 1890, pp. 80 and 84; Benson and Bartrum, 1935, p. 145) and those of Stewart Island mentioned by McKay, seem to be highly feldspathic. Park (1926, pp. 384-6) describes an aplite from the Green Islets, 12 miles south-east from Preservation Inlet and part of the plutonic mass; it contains only 0.67 per cent of Fe_2O_3 (No. 11, Table I). Some time ago Messrs H. W. Wellman and R. W. Willett of the Geological Survey found a highly feldspathic dyke traversing metamorphic rocks on the south side of George Sound about 4 miles from the entrance. The dyke is from 4 feet to 18 feet wide, exposed for a length of 40 feet, and consists of rock containing 90 per cent of oligoclase, the rest being quartz. Several hundred tons of feldspar could readily be mined opencast.

VOLCANIC ROCKS

Rocks of the same general composition as the granites and pegmatites, which consolidated within the earth's crust, reached the surface and solidified there. These are the lavas and fragmental volcanic rocks known as rhyolites, dacites and acid andesites. Among them are rocks containing a high enough proportion of feldspar and a low enough proportion of iron for potters to use as fluxes. In New Zealand, rocks of this type that may have use as Cornish stone occur in the North Auckland, Hauraki-Rotorua, Banks Peninsula, Malvern-Hills—Mount Somers and Dunedin districts.

North Auckland Volcanic Rocks

Light-coloured lavas occur as dykes and flows or have been forced up through vents in a state too viscous to flow and have built up hills on the surface. There are also in North Auckland bedded deposits of fragmental volcanic material of similar composition. These rocks consist essentially of feldspars and quartz, the accessories being ferromagnesian minerals and iron oxides. Usually they contain about 60 per cent. of feldspars. In most cases only a single sample from each of the localities has been analysed and as the different deposits may be built up of several extrusions of somewhat different ages, the composition of the whole may not be uniform. For this reason some occurrences are mentioned even though the compositions so far determined are unsatisfactory. On the other hand further sampling

may show that a satisfactory analysis may not be representative of a deposit as a whole. In addition to those mentioned other similar deposits may be present in parts of the region not yet mapped in detail.

According to Bartrum an albitic granophyre "outcrops on the west flank of Mount Camel a little north of the rocky islet near the entrance of Hohoura Harbour, and extends from near beach level to an altitude of at least 500 feet" (1929, p. 358). This rock, of which an analysis is given in Table III, No. 1, is exceptionally low in iron and lime content.

South of Lake Omapere the volcanic hill Putahi rises in smooth slopes a few hundred feet above the flats. It lies about two miles north of Kaikohe and covers about a square mile, but similar rock, largely decomposed to clay and in part concealed by basalt, outcrops in neighbouring areas. The single analysis available was of a sample containing 4.16 per cent of Fe_2O_3 (Bell and Clarke, 1909, p.73).

Ten miles north-east from Lake Omapere fragmental acid volcanic rocks occupy several square miles of country and rise in Maungaparerua to 814 feet above sea level. The rocks are much decomposed and no sample has been analysed.

Hikurangi Mountain, which rises precipitously to 1,204 feet, covers an area of about a square mile west of Hikurangi Township, 17 miles north of Whangarei. The single analysis shows that the sample contained 62 per cent of feldspar and 3.78 per cent of Fe_2O_3 (Ferrari *et al.*, 1925, pp. 74-5). "Hand specimens from different parts of the Mount Hikurangi mass show notable variety" (*Ibid.*, p. 66). The rock is classed as an acid andesite and in composition closely resembles other lavas and dykes occurring abundantly in the Whangarei area.

Maungarei (1,260 ft) forms a compact group of steep hills covering some 3 square miles of country 5 or 6 miles north-north-west from Whangarei. The single analysis was of a sample containing 60 per cent of feldspar and 3.12 per cent of Fe_2O_3 . The rock is classed as andesitic dacite. As the hill group is probably complex in structure, material of similar composition but with less iron may yet be found in accessible localities.

Parahaki, immediately north-east from Whangarei, covers two square miles and rises to 794 feet. The rock of which the mass is composed is classed as a trachytic dacite. No analysis seems to have been made.

A smooth low hill (370 ft) occupying less than a square mile occurs east of the north end of McLeod Bay, an open indentation of Whangarei Harbour. A single analysis was of a sample containing 54 per cent of feldspar and 1.16 per cent of Fe_2O_3 (Table III, No. 2).

There are a number of irregular masses and dykes of acid volcanic rock about Whangarei Head; Busby Head and the ridge extending thence north for over half a mile are made up of trachytic dacite of which an analysis of a sample (Table III, No. 3) showed 65 per cent of feldspar and 1.63 per cent of Fe_2O_3 . A dyke 15 chains north of the wharf at Urquhart Bay contains 67 per cent of feldspar and 2.41

per cent of Fe_2O_3 (*Ibid.*, pp. 74-6). Another rock 20 chains west of Big Point and 100 chains east of Busby Point is classed as a biotite-granite porphyry. It 'forms a massive wide-jointed outcrop' and is thought to be 'the intrusive equivalent of the dacites of trachytic type' common in the Whangarei district (*Ibid.*, pp. 61-2). This rock is so remarkably low in iron (1925, pp. 74-6) that a cheek sample was obtained and analysed, the iron stain on the joint faces being removed. The result (Table III, No. 4) confirms that of twenty years ago. The analyst states that the 'material heated to $1,250^\circ\text{C}$, gives a perfectly white glassy mass'. Unfortunately the locality is not easy of access. Another sample with heavy iron staining on the joint faces contained Na_2O , 3.04 per cent; K_2O , 2.74 per cent; and Fe_2O_3 , 2.40 per cent (Dom. Lab. Memo., 6/8/47, N, 1146).

Twenty-five miles south of Whangarei, in the Mangawai-Maungaturoto district, acid volcanic rocks cover some 15 square miles of country mostly south of the prominent fault scarp that bounds the Waipu hills. There are small isolated masses at the Bream Tail and Mangawai North Head but the main areas lie just west of the watershed of the North Auckland Peninsula. Analyses of four samples are available (Ferrar, 1934, p. 62) and that containing the least amount of iron is quoted (Table III, No. 5); but all are similar and the most ferriferous contains only 2.11 per cent of Fe_2O_3 .

Volcanic Rocks of Hauraki-Rotorua and Taupo Districts

Vast deposits of light-coloured volcanic rock, occupying thousands of square miles of the Rotorua-Taupo region, extend north along the east side of Hauraki Peninsula, reaching even the Great Barrier, and west into the upper basins of Waipa, Mokau and Wanganui rivers. These rocks consist largely of fragmented volcanic glass and, on account of their probable mode of extrusion, have come to be known as ignimbrites. In these regions also are masses of acid volcanic rock that either have flowed on the surface or, too viscid to flow, have been forced to the surface and accumulated in dome-like masses over the vents from which the ignimbrites had been discharged. These non-fragmented rocks may be glassy or stony and often contain spherulites, which may constitute the bulk of the rock.

There are a dozen analyses of the acid fragmental volcanic rocks chiefly from the Waihi district and Arapuni Gorge (Henderson and Bartrum, 1913, pp. 79-80; Henderson, 1920, p. 225; Morgan, 1924, p. 70; Henderson and Grange, 1926, p. 70; Grange, 1937, p. 63). All are much alike though there are minor differences. The majority were of samples containing more than 2 per cent of Fe_2O_3 ; only one shows less than 1 per cent (Table III, No. 6). This is of a sample from the rock mass on which Arapuni Dam is built; but another sample from the same deposit contained 4.79 per cent of Fe_2O_3 .

The acid non-fragmented volcanic rocks form large or small areas in general surrounded by ignimbrite and scattered irregularly in the region. They are classed as rhyolites, dacites and acid andesites. Sixteen analyses are available (Henderson and Bartrum, 1913, pp. 79-80; Morgan, 1924, p. 70; Grange, 1937, pp. 66-68; Bartrum, 1913, pp. 139-40) as well as four from Mayor Island (Marshall, 1936, p. 343). Two

only of these show less than 1 per cent of Fe_2O_3 . That of a sample from Paku 'Island', the peninsula forming the north head of the estuary of Tairua River, is given in Table III, No. 7. This rock is made up almost entirely of large spherulites which consist of radiating fibres of feldspar with interstitial glass and quartz. The other low-iron sample is from Omaha, a rather inaccessible locality on the Hauraki water-shed about a dozen miles north-east from Waihi (Park and Rutley, 1899, p. 467).

Volcanic Rocks of Banks Peninsula

The complex mass of volcanic and other rocks forming Banks Peninsula consists chiefly of basalts and andesites. There are, however, considerable exposures of rhyolites and, less abundantly, of trachytes. Speight has discussed the geology of this district in a number of papers, of which only a few are listed in this paper, and his maps show, in a general way, the distribution of the rocks of interest to the potter.

Rhyolitic material covers an area of about two square miles at the Head of the Bay, Lyttelton Harbour, forming Manson Peninsula, the ridge trending south-west from it, as well as parts of Quail Island and Potts Peninsula. Farther south similar rocks occupy an area several times as large between Gebbie and McQueen valleys, occur round their heads, and extend across the divide into the fall of Lyttelton Harbour. These rocks consist essentially of feldspar and quartz and the five analyses that Speight cites show an average Fe_2O_3 content of only 1.05 per cent, an amount decidedly lower than that of similar rocks of the North Auckland and Waihi-Rotorua-Taupo districts. Speight (1922, p. 89) notes the "general uniformity in chemical and mineral composition" of these rocks. Analyses Nos. 8 and 9 of Table III, quoted from Speight, are of specimens from widely separated localities.

Innumerable dykes of different compositions and textures cut the volcanic rocks of Banks Peninsula. They are the late differentiates of the magma or magmas that supplied the main centres of eruption; the great bulk of their material is high in alkali and richly feldspathic. Some of the rocks are also low in iron and these may have value as a source of flux to the potter.

Speight (1923, p. 143) described "a dyke forming a great curly mass on the south shore of Quail Island and sending tongue-like apophyses into the neighbouring rocks. It is white or creamy-white in colour, but with coatings of iron-oxide on the joint planes." He noted that the rock consists almost entirely of feldspars and classed it as a trachyte with bostonitic affinities. Further, he suggested that such a rock may prove to be a source of feldspar for insulators and porcelain. The analysis, No. 10, Table III, is quoted from his report. In the same publication, Speight (1923, p. 147) describes a dyke, 6 feet thick, just north of the neck of Onawe Peninsula, Akaroa Harbour, which owing to its hardness stands out conspicuously on the shore. This is composed of nearly pure feldspar rock coloured slightly with oxides of iron. Its analysis is given as No. 11 of Table III. Speight also describes and gives analyses of other trachyte dykes of Banks

Peninsula, some containing a higher percentage of feldspar than the two quoted, but with higher iron contents.

Volcanic Rocks of Malvern Hills and Mount Somers Districts

The work of Haast, F. W. Hutton and S. H. Cox make the geology of the Malvern Hills and Mount Somers districts familiar to New Zealand geologists, but this account of some of the volcanic rocks is derived mainly from the descriptions of Speight, who mapped both areas in detail (1928, 1938).

Rhyolites and pitchstones outcrop along the south slopes of the Malvern Hills west from White Cliffs to Rakaia Gorge. They cover in all about ten square miles of country, form Mount Misery (1,910 ft) and Pullwood Peak (2,403 ft), and are extensively exposed along the north and south flanks of Rockwood Range, which culminates in High Peak (3,176 ft). In addition, outcrops occur along and near the Rakaia Gorge. Speight (1928, p. 16) and P. T. Cox (1926, p. 98) give analyses of acid rocks which contain from 53 to 60 per cent of feldspar, the rest of the rocks being chiefly quartz. The content of Fe_2O_3 ranges up to 2.41 per cent. The analysis of the rock containing least iron is given as No. 12 of Table III.

In the Mount Somers district, Speight's maps show that much of Mount Alford (3,843 ft) and Mount Somers (5,536 ft) consists of rhyolitic rocks which cover in all about 20 square miles of country. He cites four analyses of glassy and microcrystalline acid rocks all of very similar chemical composition (1938, p. 33). The silica ranges from 76.81 to 74.22 per cent and the Fe_2O_3 content from 1.06 to 1.49 per cent, the averages being respectively 75.05 and 1.33 per cent. Daly (1914, p. 19) gives 72.6 per cent and 2.3 per cent as the corresponding means of 64 rhyolites and liparites; so that on the four samples analysed the Mount Somers acid rocks are rather high in silica and decidedly low in Fe_2O_3 . The normative composition of these rocks is 57 per cent of feldspars and 38 per cent of quartz. The iron, as in Malvern Hills rocks, is present for the most part as an iron garnet and biotite and would no doubt be reduced by magnetic separation during or after grinding. The analysis of the rock showing least iron is given as No. 13 of Table III.

Volcanic Rocks of the Dunedin District

The rocks of the volcanic district of Dunedin are known through the numerous reports, here mostly unlisted, of Professors P. Marshall and W. N. Benson. The former (1906, 1914) gives the more general survey and includes in his account the flows and dykes of interest to the potter. These are the trachytes outcropping along the west shore of Otago Harbour north and south of Port Chalmers, forming Quarantine Islands, and covering several square miles of Otago Peninsula west and north of Hooper Inlet. These exposures are along the north-west-striking Portobello-Port Chalmers Anticline (Benson, 1941, p. 216), which brings to the surface rocks low in the eruptive sequence. The other well-known outcrops at North Head and Omihia lie on a parallel line some miles to the north-east. The trachytes, which

occur in dykes and massive flows, are light-coloured rocks, generally iron-stained, and consist almost wholly of feldspar. Only two analyses are available, one of a sample from North Head (No. 14, Table III) and the other of a sample from Portobello (Marshall, 1906, p. 399). Both are low in iron; soda feldspar constitutes 60 per cent. of the rock, potash feldspar 30 per cent, and lime feldspar 5 per cent. The composition is so favourable that if the analyses are reasonably representative of the rocks as a whole, search should be made for outcrops of similar suitable material in more accessible localities.

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TABLE I. ANALYSES AND NORMS OF ACID PLUTONIC ROCKS LOW IN IRON

	1	2	3	4	5	6	7	8	9	10	11
ANALYSES:											
Quartz	72.28	72.97	73.00	68.05	74.75	75.05	74.75	72.42	67.08	77.28	73.87
Orthoclase	14.90	15.06	15.32	18.25	13.39	14.74	13.77	15.61	17.87	11.12	14.67
Albite	0.50	0.54	0.30	—	0.57	0.16	0.60	None	1.12	0.33	0.20
FeO ₃	0.15	0.34	0.35	—	0.46	0.36	0.58	0.79	1.12	0.42	0.42
MgO	0.15	0.14	0.15	—	0.23	0.05	0.36	0.11	0.22	0.75	None
CaO	1.66	1.71	1.53	1.00	0.78	0.78	0.30	0.27	0.61	0.75	0.82
Na ₂ O	3.01	5.20	5.46	3.16	4.18	4.32	4.51	1.92	2.34	1.89	5.00
K ₂ O	5.25	3.17	2.88	7.25	4.68	4.02	4.30	8.53	9.43	6.95	4.02
Water above 105°C.	0.68	0.47	0.43	0.30	0.30	0.41	0.17	0.60	0.97	0.52	0.23
Water below 105°C.	0.13	0.21	0.17	0.30	0.18	0.20	0.23	0.04	0.07	0.13	0.21
CO ₂	0.08	0.08	None	—	0.10	None	None	None	None	—	None
TiO ₂	0.05	0.07	None	—	0.12	0.07	None	0.02	0.07	0.02	0.03
ZnO	Trace	None	0.09	—	0.01	—	—	—	—	—	None
P ₂ O ₅	0.83	0.04	0.10	—	0.08	0.04	0.12	None	0.19	0.35	0.15
SiO ₂	None	None	Trace	—	0.02	0.03	—	0.03	0.03	—	None
CaO ₃	—	None	None	—	None	—	—	—	—	—	None
NiO	—	None	None	—	None	—	—	—	—	—	None
MnO	0.01	0.02	0.04	—	0.02	0.10	0.06	0.01	0.28	0.01	0.33
SrO	—	0.04	Trace	—	—	—	—	—	—	—	0.04
BaO	—	0.13	0.13	—	0.04	—	—	—	—	—	0.04
NORMS:											
Quartz	99.70	100.19	99.95	—	99.87	100.36	99.75	100.45	100.76	100.11	100.03
Orthoclase	31.06	18.76	26.58	19.88	—	—	31.02	—	55.80	41.12	23.79
Albite	25.51	44.07	17.24	42.85	27.63	23.79	25.58	50.48	19.83	16.02	12.37
Anorthite	8.26	8.51	46.11	26.74	33.75	35.09	38.25	16.27	2.89	2.37	3.89
Total Feldspar	64.83	71.34	70.86	74.54	65.08	62.58	64.38	68.03	78.52	59.51	70.05
TOTAL IRON CONTENT AS Fe ₂ O ₃ :											
Fe ₂ O ₃	0.50	0.92	0.69	—	1.08	0.56	1.24	0.88	1.60	0.63	0.67

No. 1. Granite ("hard purple" china stone) Goonvean, Cornwall. (Howe, 1914, p. 192). The total contains 0.88 per cent. of fluorine and small amounts of lithia and chlorine.

No. 2. Granite, at contact of granite and quartzite, Pease Stream, Wangapeka River, Dom. Lab. Memo. 3/12/25. (Q. 2072).

No. 3. Granite, Brewery Creek, Owen River. Dom. Lab. Memo. 12/12/30. (V. 3182).

No. 4. Pegmatite, Baton Road, Nelson. Dom. Lab. Memo. 28/8/42. (H. 2756).

No. 5. Aplite, Dart River, 1 mile upstream from Wangapeka River. Dom. Lab. Memo. 10/12/24. (P. 1576).

No. 6. Small vein of Microgranite, Mount Albert, Reefton District. (Henderson, 1917, p. 109-110).

No. 7. Aplite, Old Karamea Inland Track, Westport District. (Morgan and Bartrum, 1915, p. 105-6).

No. 8. Pegmatite, large mass containing garnet, Otututu River, Paparoa Mountains, Greymouth District. (Henderson, 1917, p. 109-110).

No. 9. Coarse pegmatite, Mica Mine, Charleston. (Morgan and Bartrum, 1915, p. 105-6).

No. 10. Granite, Stewart Island. (Williams, 1934, p. 323 and Table III). There is also a trace of fluorine.

No. 11. Aplite, C. Islets, Fiordland. (Park, 1926, p. 384-6).

TABLE II. LABORATORY TESTS OF CLAY FRACTIONS
FROM DECOMPOSED GRANITES, NELSON

Sample No.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Percentage clay		18		26		40	30	32
Plasticity	none	none	fair	none	fair	extremely low	moderate	fair
Colour of tile	light brown	white	fawn	white	light brown		cream	dull white
Raw strength	very weak	very weak	strong	very weak	weak			
Percentage Temper- ing water	33	26	20	21	28			
Linear-shrinkage per cent.								
95°C.	1.6	1.6	3.2	1.6	4.7	2.0		
950°C.	1.6	1.6	4.7	0.0	6.3	*1.5	*3.2	*4.7
1050°C.	3.2	3.2	7.8	0.0	10.9			
1150°C.	14.1	10.9	9.4	10.9	14.1	12.5	12.5	14.1
Na ₂ O content	2.46	1.80	1.33	1.83	1.43	5.74	3.55	2.88
K ₂ O content	2.32	1.62	2.00	2.50	2.06	2.78	2.54	2.06
Alkali-feldspar content	44.7	25.3	23.3	30.3	24.3	64.9	45	35.3

(1) Waiwhero Valley (L. 493-5).

(2) Ngatinoti Road (L. 493-3).

(3) Orinoco Road (L. 493-4).

(4) and (5) Boyd's, Sherry Valley (L. 493-1, 2).

* (6), (7) and (8) Baton Saddle (see Taylor, 1943, p. 83).

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